AUGUST 19, [illegible]
CHEMICAL & ENG[illegible]ERING

NEWS

[illegible]cts & Figures for Chemical R&D

Page 32

CHEMICAL & ENGINEERING
NEWS
AUGUST 19, 1991

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News of the Week

■ **A plan to destroy Iraqi chemical weapons has been submitted to the United Nations and, if approved, could be undertaken fairly soon.** Page 6

■ **Pact between an Arizona electric power plant and an environmental group would cut sulfur dioxide emissions 90%, reducing haze that often obscures the Grand Canyon.** Page 7

■ **On just concluded mission of space shuttle *Atlantis*, biochemist astronaut performs chemical-related experiments under microgravity conditions.** Page 7

■ **Eastman Kodak is restructuring again and plans to reduce its imaging and information systems work force by 3000, mostly by early retirement.** Page 7

■ **Some chemical and other nonelectric uses of concentrated solar energy show promise, says a study by a National Research Council panel.** Page 8

■ **Frederick E. Bailey, director on the ACS Board from Region II, has died at the age of 63.** Page 8

Cover: Photo courtesy of Bristol-Myers Squibb

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Business

Ethylene glycol production in the U.S. will falter this year, but rising demand—possibly amounting to about 5.3 billion lb—will be met by drawing down inventories of this key ingredient for antifreeze. **Page 11**

Government

Chemical weapons treaty with teeth is urged by Democratic Rep. H. Martin Lancaster, a leading Congressional voice pushing for a global ban on such arms. **Page 15**

Education

Pacific Rim nations assess their future technical education needs in light of current economic realities as they strive to better prepare their countries for competition in the international marketplace. **Page 21**

ACS News

ACS education programs ranging from elementary school to college level get major boost from grants from such funding sources as NSF and the society's Campaign for Chemistry. **Page 74**

Chemical R&D

C&EN's annual compilation of data on chemical R&D shows modest growth for 1991, with overall spending in the U.S. likely to top $151 billion, a 4% increase over last year. **Page 32**

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LETTERS

Keeping the word chemical

Ronald J. Gillespie made a particularly interesting point in his letter (C&EN, Dec. 10, 1990, page 4). The word chemical is not defined in chemistry texts! Gillespie notes that "chemists often use the word in the sense of a substance produced by the chemical industry." The "World Chemical Outlook" feature in the same issue certainly reinforces that point.

Examples cited in the letter suggest that it is common for nonchemists, too, to recognize the history of a sample of matter in selecting what term to apply. Usage seems consistent with the definition of chemical as a sample of substance produced, extracted, or marketed in a consistent form. Dioxygen industrially separated from the atmosphere is thus a chemical, but not what we breathe. Ozone generated from water purification is a chemical, but not that formed in the stratosphere. Sucrose producers become chemical firms, but the sugar contained in a raisin is just a constituent, not a chemical.

Gillespie is certainly not the only chemist objecting that "chemical" involves a sample's origin as well as its changing composition. Yet there would be great difficulty in changing the common concept. For example, it would be interesting to learn of marketing research results related to the 1989 National Chemistry Week campaign to have students label everything with "This is a product of chemistry" tags. The idea may be acceptable to chemists, but I suggest the paradigm shift for the public was too challenging to be accomplished except with an unusual degree of local backup.

It is folly to expect that "chemical" might go unused because chemists abandon it due to a current, pejorative sense to the word. Some public perception of danger is valid; in the concentrated form we use, many chemicals are poisonous. Rather than trying to sidestep this fact by going to "substance," let us use "chemical" with pride. Think of an example from your own experience to get you started. General acceptance of the definition above may benefit chemistry by clarifying the equivalence of some chemicals and valued materials referred to by application names: detergent, pigment, medication. (See David Shobe's letter, C&EN, Dec. 17, 1990, page 2.)

It is true that dictionary definitions of chemical are poorly differentiated from substance. I suggest that chemists work to tighten up the definition, rather than do away with the word.

James A. Carroll
Department of Chemistry
University of Nebraska
Omaha

Chemical Bank and Manufacturers Hanover have just announced their pending merger, and the name they have chosen to keep for the merged bank is Chemical Bank. Perhaps this will put a little spirit into the society's members quivering over the word "chemical."

Michael Macomber
Kensington, Calif.

Radon and lung cancer

My repeated attempts to question the Environmental Protection Agency about the low level of 4 picocuries (pCi) per L as a hazard level for radon gas in homes has met with little success. It appears that radon is guilty until proven innocent of causing lung cancer.

EPA claims that "the harmful effects of radon do not appear until many years after exposure." This type of statement has been used to cause public alarm for many chemicals. Radon is not a new man-made chemical. The effects of radon have happened in the past, are happening now, and will happen in the future. Therefore, we can evaluate the deaths from lung cancer today and not have to wait.

Earl Ubell reported in November 1990 that "of the 140,000 deaths from lung

Corrections

- July 1, page 43: 1-Trimethylsilylpropyne is available in the U.S. from Aldrich Chemical as well as from Hüls America.
- July 29, page 20: *Materials & Processing Report* is published by Elsevier Science Publishing Co., New York City. Renée G. Ford is its editor.
- Aug. 5, page 4: The photograph of the tankcar derailment at Dunsmuir, Calif., should have been credited to Jay Mather, *Sacramento Bee*/SYGMA.

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Ethylene Glycol Supplies Will Be Sufficient To Meet Rising Demand

Producers of this glycol, the key ingredient in antifreeze, plan to offset small decline in production this year by drawdown of inventories

Bruce F. Greek, C&EN Houston

As winter, the season of highest consumer demand for antifreeze, draws ever closer, producers of ethylene glycol, the key ingredient in antifreeze, believe that supplies will be sufficient to meet U.S. demand and export needs. What's more, they think there will be enough for glycol's other uses, too, including polyester fiber, film, bottle and engineering resins, and several small-volume specialty uses.

Ethylene glycol production in the U.S. this year will likely be down about 300 million lb from last year, to about 4.6 billion lb, the result of an explosion and fire at an ethylene oxide unit of Union Carbide's Seadrift plant in Port Lavaca, Tex. (C&EN, March 18, page 6). About 500 million lb of ethylene glycol will be imported, mostly from Canada, for a supply total of about 5.1 billion lb.

Consumption is expected to rise this year as the recession continues to ease, possibly increasing to about 5.3 billion lb. The excess glycol will come from a drawdown of inventories, a reversal of the situation last year when production and imports at 5.5 billion lb exceeded U.S. demand and exports by about 300 million lb.

Producers other than Carbide are expanding ethylene glycol output, partially to offset the lost production. For example, PD Glycol (a joint venture of Du Pont and Occidental Chemical) added 100 million lb of capacity at its Beaumont, Tex., plant at the start of the third quarter.

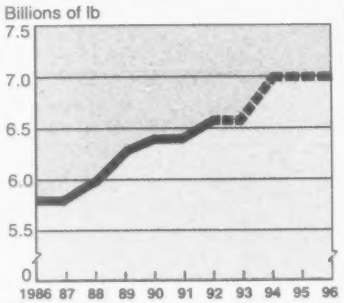
Total U.S. capacity to make ethylene glycol at the beginning of this year was about 6.4 billion lb. About 5.7 billion lb of the capacity makes monoethylene glycol, the most commercially significant compound. Di- and triethylene glycols are made in much smaller quantities along with monoethylene glycol and go into some of the same applications. (Unless otherwise indicated, ethylene glycol in this article means the mono form.)

Despite lower U.S. production, world output of ethylene glycol is expected to reach about 19 billion lb this year. This will mark an increase of more than 2% from less than 18.5 billion lb in 1990, says M. Peter Bellis, vice president of Chemical Marketing Associates Inc. (CMAI) in Houston. World consumption will grow at an average annual rate of 4.4% from 1991 to 1996, according to CMAI's recently released study, 1991 World Ethylene Oxide/Ethylene Glycol Analysis, the preparation of which Bellis directed.

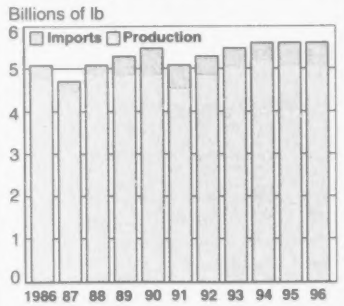
In the U.S. and Western Europe, polyester resins for bottles, film, and engineering uses will spur ethylene glycol growth, Bellis says. Polyester fiber production will be the driving force behind consumption growth in the Far East.

Despite a sizable capacity expansion now coming on stream in South Korea, and despite more capacity currently under construction or planned for in that country and in other Asian locations, imports will be needed to meet the demand in the Far East. Part of this demand for imports will be supplied by new capacity built in Canada and Saudi Arabia. U.S. exports to the Far East will remain sizable, although Bellis

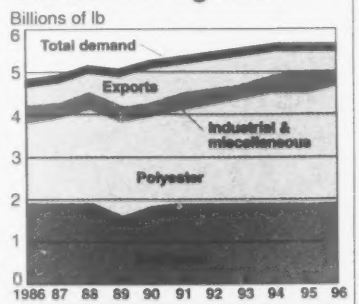
U.S. ethylene glycol capacity grows . . .



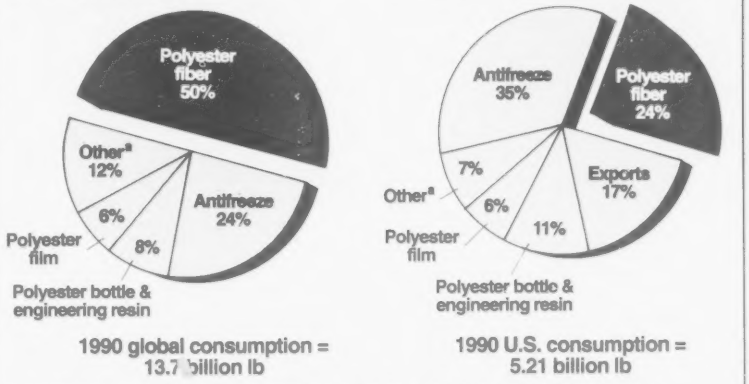
. . . as imports' share of supply shrinks . . .



. . . and lower exports offset demand growth



Note: Data for years 1991–96 are forecasts.
Source: Chemical Marketing Associates



Note: Data are for monoethylene glycol. **a** Includes chemical reactants, coatings, solvents, and comonomers in unsaturated polyester and acrylic resins. **Source:** Chemical Marketing Associates

forecasts that they will decline slowly over the next five years. Western Europe will continue to import glycol because a growing share of ethylene oxide production in that region will be used to make more profitable derivatives.

Global consumption patterns for ethylene glycol differ significantly from those in the U.S. Polyester fiber accounts for half of world use, and antifreeze makes up less than a quarter. In contrast, in the U.S. more than one third goes into antifreeze and less than one fourth goes for making polyester fiber. Exports of glycol, particularly to the Far East, were more than 870 million lb, more than a sixth of U.S. consumption in 1990.

Last year, a large share of growth in U.S. demand for ethylene glycol (up 3.9% over 1989) resulted from a rebound in the demand for antifreeze. Sales of ethylene glycol-based antifreeze in the U.S. amounted to more than 192 million gal, according to a survey conducted by the Chemical Specialties Manufacturers Association. Sales last year were up more than 19% over the 161 million gal sold in 1989.

Antifreeze consumption this year will amount to about the same as in 1990, according to most industry sources. For example, lower automobile production reduces the original fill use of antifreeze, but that situation is offset by increased demand for replacement material, because cars are kept on the road longer, points out Ronald L. Gist, a senior consultant at Pace Co. in Houston. Earlier this month, there was almost no concern about antifreeze supplies for the coming winter, Gist says, despite indications that inventories of ethylene glycol will be reduced this year.

Growth in use of ethylene glycol in antifreeze will be low worldwide between 1991 and 1996, at 0.9% annually, according to the CMAI analysis. U.S. growth is forecast at even less—0.6% annually—which suggests that the historical pattern of large swings in annual antifreeze sales will continue.

Polyester fiber uses of ethylene glycol in the world, now slightly less than 50% of the total, will grow 5.1% annually through 1996 or faster than total consumption at 4.4% annually. By 1996, fiber uses will be 52% of total world consumption, or about 9.3 billion lb, according to the CMAI study.

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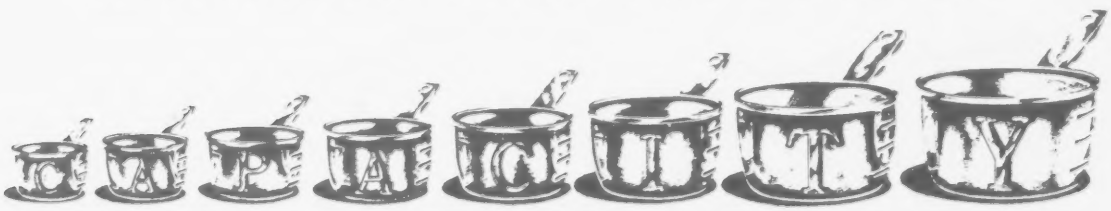

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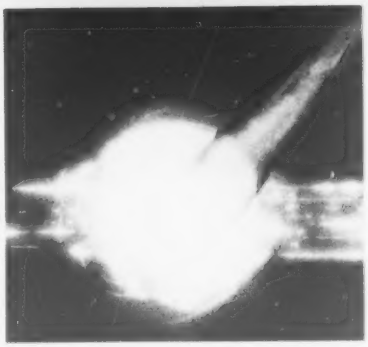
U.S. demand for polyester fiber will grow an average 1.8% a year through 1996 and will account for nearly 25% of glycol consumption. The slow growth stems from modest recovery in fiber demand following a downturn in the 1990–91 recession.

The brightest outlook for polyester use of ethylene glycol both globally and in the U.S. is for bottle and engineering resins. Bellis estimates worldwide growth at 9.7% annually through 1996, just ahead of U.S. growth of 8.5% annually. By 1996, U.S. bottle and engineering resins will require 16% of total glycol consumption, up from about 11% in 1990. Global use for these resins will take 11% of total consumption, up from less than 9% in 1990.

Polyester use for film also is expected to grow faster than fiber use, both worldwide and in the U.S., but only about 60% as fast as in bottle and engineering resins. Because of stringent performance requirements of the end uses of polyester films (such as in photographic and magnetic media), the resins are purified more than those used in making fibers, rendering ethylene glycol quality requirements even higher.

Quality requirements for the ethylene glycol that goes into polyester resins make that glycol more expensive to manufacture than antifreeze or industrial grades. There typically is a spread of 1 to 2 cents per lb between fiber and antifreeze grade prices. Currently, contract ethylene glycol prices range from 21 to 23 cents per lb for fiber grade and 20 to 22 cents per lb for antifreeze grade. Spot prices on the Gulf Coast are 1 to 2 cents lower than contract prices. By the end of the third quarter, prices are expected to decline again 0.5 to 1 cent per lb.

Prices of ethylene glycol are falling, as are the prices of all major ethylene derivatives, because ethylene prices continue to decline. However, partially because of the expected shrinkage of ethylene glycol inventories, relative prices have declined less than ethylene prices. Next year when all existing capacity is operable and expansions and process improvements are complete, prices may decline more rapidly as inventory is rebuilt. □



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Pacific Rim Nations Assess Future Technical Education Needs

Conference on science and engineering education systems of Pacific Rim countries focuses on readjustments needed to succeed globally

Joseph Haggin, C&EN Chicago

Most of the Pacific Rim, by some accounts, is living on the sharp edge of economic disaster. To stave off this threat, some countries are putting increased emphasis on planning for their technological futures. They are starting with the universities, where the engineers and other technical professionals of the future will be trained.

Likely technological emphases for the rest of the 1990s are accelerated energy production, the emergence of new materials, further "revolutions" in telecommunications, better housing, and environmental improvement. All of these technological efforts will need to evolve in the face of increasing population pressures, especially in the developing nations, and the need to improve living standards around the world.

One of the keys to success in these technological areas will be more and better engineering education. Globalization is no longer limited to industry, politics, and economics. Engineering education also is becoming distinctly globalized, and this poses many unique challenges for educators and the profession alike.

To assess the problems of engineering education common to the Pacific Rim countries, the University of Illinois, Chicago, convened a conference on the subject last month. Called "Engineering: A Global Enterprise," the conference was jointly chaired by Paul M. Chung, dean of the university's college of engineering, and James P. Hartnett, professor in the college's mechanical engineering department. Representatives from such Pacific Rim nations as China, Taiwan, South Korea, and Japan attended, along with U.S. representatives. The Japanese, though, kept a low profile at the meeting.

Since World War II, the flow of technology transfer and technical education has been from western nations to eastern ones. This situation, however, is now changing considerably.

Strong growth at Chinese universities in past 40 years

	1990	1980	1978	1949
Universities	1,075	675	598	205
Engineering schools	285	203	184	28
Undergraduates	2,065,900	1,143,700	856,300	116,500
Engineering students	745,600	383,500	287,600	30,300
Graduate students	84,158	21,604	—	—
Engineering graduate students	38,470	7,206	—	—
Teaching and administrative staff	1,004,700	631,900	516,400	46,000
Academic faculty	394,500	246,800	206,200	16,100

Source: Office of the President, Tianjin University, China

Korean science, engineering enrollments have blossomed

		Number of departments	Number of degrees awarded B.S.	M.S.	Ph.D.	Faculty	Student to faculty ratio
1965	Science	108	9,331	281	10	751	13.2:1
	Engineering	130	17,332	312	3	540	33.2:1
	TOTAL	**238**	**26,663**	**593**	**13**	**1291**	**21.6:1**
1970	Science	126	12,972	319	35	870	15.7:1
	Engineering	232	22,817	509	19	932	15.6:1
	TOTAL	**358**	**35,789**	**828**	**54**	**1802**	**20.8:1**
1975	Science	141	14,472	713	154	1128	14.4:1
	Engineering	268	43,005	1,285	131	1300	35.3:1
	TOTAL	**409**	**57,477**	**1,998**	**285**	**2428**	**25.6:1**
1980	Science	290	31,338	2,145	463	1739	21.0:1
	Engineering	478	99,568	5,154	630	2340	47.5:1
	TOTAL	**768**	**130,906**	**7,299**	**1093**	**4079**	**36.0:1**
1985	Science	409	83,743	3,805	1424	3194	29.5:1
	Engineering	476	189,069	8,822	1712	3600	58.4:1
	TOTAL	**885**	**272,812**	**12,627**	**3136**	**6794**	**44.8:1**
1990	Science	419	94,419	3,897	1487	4057	21.6:1
	Engineering	720	239,436	11,861	2898	5038	50.4:1
	TOTAL	**1139**	**333,855**	**15,758**	**4385**	**9095**	**38.9:1**

Source: Office of the President, Seoul National University, South Korea

Telecommunications: vital to global competitiveness

Training a population to be competitive in the global marketplace more and more means dealing with the "revolution" in telecommunications systems. It also means preparing to learn—and use—telecommunications systems now on the drawing board. Staying current in order to best prepare students for the demands of the technological world places a heavy, and costly, demand on technical education systems in developed countries. And it is likely to place an extraordinary demand on such systems in developing countries.

But, according to Bernard F. Sergesketter, vice president of AT&T Bell Laboratories who spoke at the recent University of Illinois, Chicago, conference, it is vital that education systems meet this demand. He believes the future health of global industry and commerce hinges on it.

The current impact of telecommunications technology may be gauged by considering some data on "fax traffic" flowing between the U.S. and Japan. About 26% of all message traffic to Japan is now fax messages. The fax traffic from Japan to the U.S. is 60% of all message traffic.

One expectation for future telecommunications developments is in the area of satellite publishing. The use of this technology is a necessity, says Sergesketter. Even more important may be the realization of the potential for fiber optics and improved computational power.

In addition to the transmission of messages by fiber optics, the optical computer will probably make available the power necessary to handle the coming revolution in software—speech processing. One very important application is human-to-human communication through natural language barriers. The software necessary for such translation is under development. It not only will permit the direct translation of messages but also will offer the user the opportunity to search any electronic database in the world. According to Sergesketter, successfully using these and other telecommunications technologies is likely to be vital to nations that will be competing in the global marketplace of the future—and to students these countries are educating to help them stay competitive.

Starting from scratch, many of the eastern countries have built formidable systems for technical education. But some constraints, derived from national philosophies and cultural beliefs, remain. In observations made after the conference, Chung noted the U.S. also has some built-in constraints that must be removed.

In the U.S., engineering education emphasizes mathematics, science, and research. As global interdependency grows, he says, engineers must be more artful in areas such as economics, international management, communications, and languages. Chung also believes engineering education should impart social, cultural, and language skills to future engineers. He believes most engineers are ill-prepared to function in an international environment.

According to Chung, U.S. engineering schools overemphasize basic science and engineering at the expense of practical design and consumer-oriented applications. For example, he observes that the U.S. education system does not teach what is in Japan a honed skill—how to use technology to produce consumer products. "Engineers must be taught to commercialize their own technology," he says. Similarly, Americans are so confident of their wealth, power, and technical dominance that engineering students are not encouraged to consider seriously the successes of other nations. He adds that 30 years ago the Pacific Rim nations began to study U.S. technology. They took what best fitted their needs and cultures, and what supported their national goals. Americans still have difficulty in extracting what works for them from the Japanese, Chinese, and Koreans.

The educational problems certainly are not restricted to the U.S.; most of the Pacific Rim countries have an equitable share. Foreign students in the U.S. may learn technology but not U.S. culture or the way Americans do business. Like their U.S. counterparts, foreign students must be equipped with the cultural and communications skills to function internationally. With a few individual exceptions, all the Pacific Rim countries represented at the conference are struggling with these problems.

A side debate going on during the conference centered on the serious consideration now being given to an international standard for engineering education. People also discussed, in private, the possibility of an international accreditation body for the Pacific region. Such topics invariably excite passions—usually negative ones—among educators.

Chung notes that international commerce is necessary for survival and that engineering is an integral part of the industrial and commercial effort. The faculties in many engineering schools are already becoming international in character. At the college of engineering of the University of Illinois, Chicago, 22 of the 115 faculty members are of Asiatic origin, 14 being Chinese, Korean, or Japanese, and eight Indonesian or Indian. In addition, many cooperative programs now are operating between universities. The University of Illinois, Chicago, now has working relationships with a number of Asian universities, including Korea University in Seoul, Tsinghua University in Beijing, and the University of Tokyo. Arrangements with universities in other parts of the world also are common.

When the educational problems are considered from another perspective, matters change considerably. Wan-Kyoo Chu, president of Seoul National University in South Korea, leaves no doubt that that university was very closely wedded to the economic prosperity of South Korea. He is worried about the developing countries running into "ever higher walls of protectionism" from the developed nations. The collapse of communism in Eastern Europe has caused a rekindling of interest in European development among capitalists. But that interest may dwindle as the problems of converting those economies from communism come into sharper focus.

Chu believes the "rising dragons"

of the Pacific have three main problems: barriers to technology transfer, the Uruguay round of the General Agreement on Tariffs & Trade, and the backward nature of their industries.

Since World War II and the Korean War, South Korea has managed to eliminate its foreign debt and boost its per-capita gross national product from $50 to $5000. At the same time, annual trade volume has risen from $10 million to $130 billion. The main reason for this nation's lack of optimism over its immediate future is its lack of scientific and technical education, which has reached the crisis stage, Chu says.

Before World War II, the colonial powers placed severe limitations on native educational institutions and did little to improve the training of administrators and other professional people. Japanese colonials established Keijo Imperial University in Seoul, but it was almost entirely populated by Japanese nationals, according to Chu. Only three Koreans received a B.S. degree in physics between 1910 and 1945. Only 30 Koreans obtained engineering degrees during the entire colonial period.

A major education-associated problem for South Korea has been finding qualified educators. Following World War II, only about a dozen such people were available to fill all the jobs in the natural sciences and engineering. Most of the potentially qualified people were employed in government or industry. As a result, most of South Korea's college graduates had to go to the U.S. to study in these fields—and many didn't return home.

Upturns in the South Korean economy in the 1960s caused college enrollments to increase sharply. By 1990, South Korea had a million undergraduates, 87,000 graduate students, and 42,000 professors. However, faculty growth has not been able to catch up with demand: The faculty-to-student ratio has dropped to 1:39 for all collegiate work and to 1:50 for engineering training. And indicators point to a worsening situation.

The first major technology institutes in South Korea were founded in 1962. A few years later the government established the Ministry of Science & Technology and, in 1970, the Korean Advanced Institute of Science & Technology. The economic setback, caused by the oil crisis of 1972–76, did not prevent educational progress. Some new institutes were established, including the Korean Institute of Chemical Technology.

South Korean science and technology is characterized by many close associations between academe and industry. The first was the Korean Genetic Research Association, founded in 1982. In 1988, 44 such associations were sponsored by 862 member companies.

Although all this association between academe and industry might indicate successful transfer of re-

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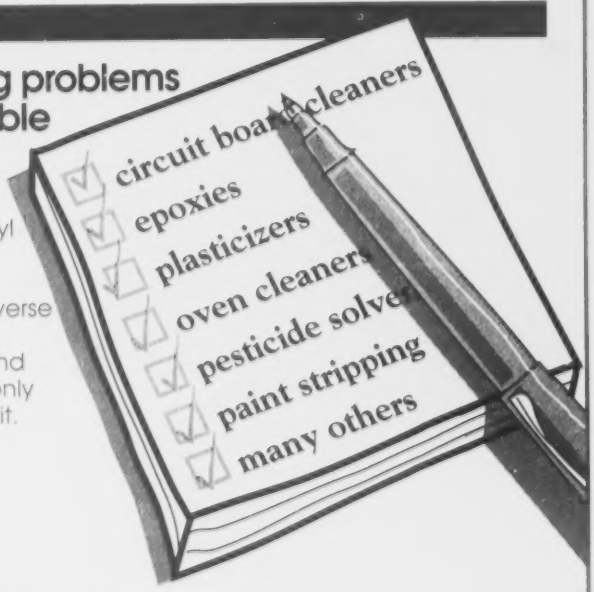

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search to products, statistics indicate economic development actually is slowing. In 1989, South Korea realized further economic development was impossible without dramatic growth in science and technology. Thus, the government enacted legislation to augment scientific and technical education.

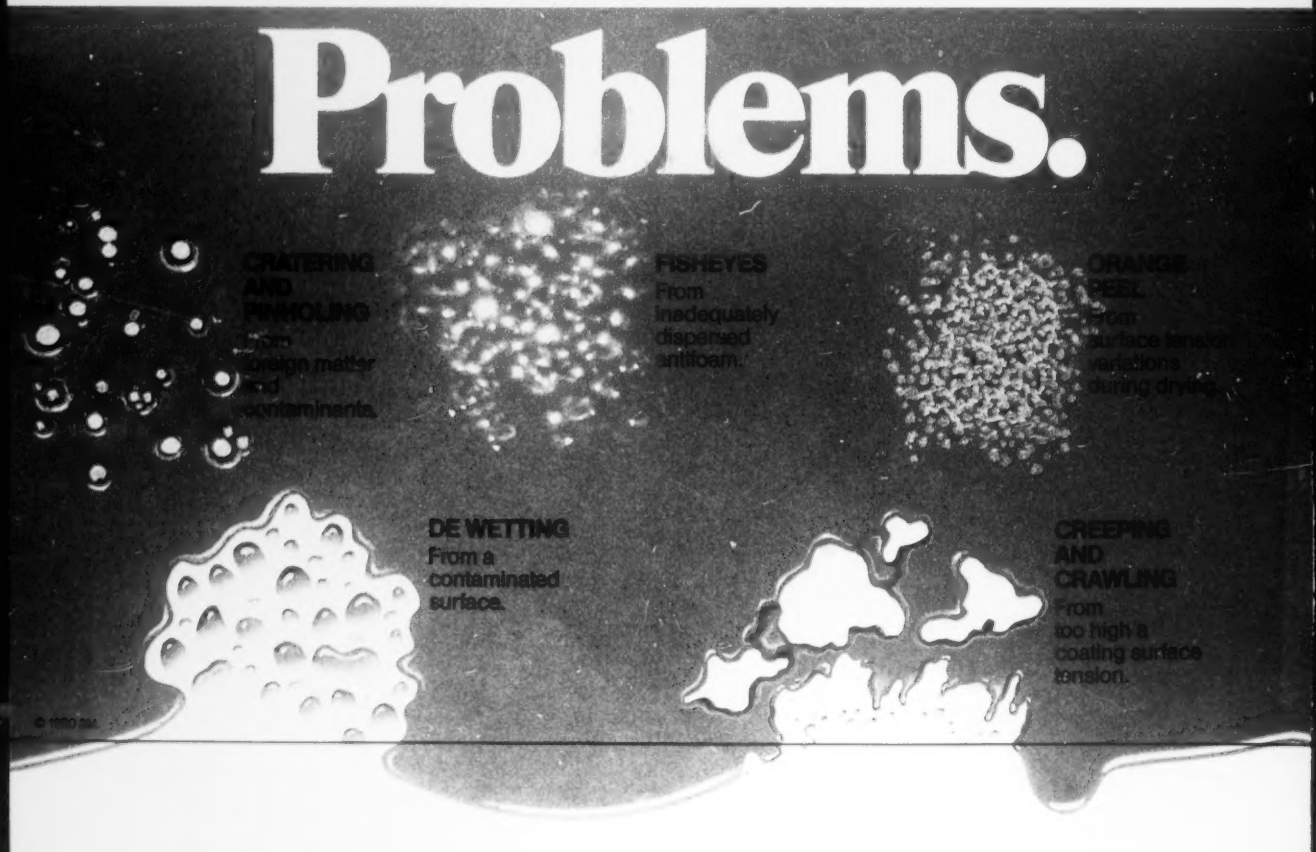
South Korea's very limited natural resources, a problem it has in common with the other "dragons," means that its economic lifeblood is imported technology, along with the technical development, through education, of its own people.

In retrospect, attendees of the conference note, South Korea should have invested more generously in science and technical education a generation ago. This is now being done, but some believe it's coming too late to have an immediate effect. The new projections for South Korea call for an average annual growth of 7.5% in GNP for the five-year period beginning in 1992. The corresponding per-capita wealth should be $11,000 in 1996. The total trade volume is projected to be $153 billion with a $3 billion deficit in 1992. By 1996, the total trade volume is projected to be $270 billion, with a surplus of $7.5 billion. Chu thinks South Korea's five-year economic plan is a bit optimistic. But if it all comes to pass, he suggests it will be more because of South Korean national grit than anything else.

In Taiwan, the situation is somewhat better. Jin-Fu Chang, a professor at National Taiwan University of Taipei, mentions a new national project aimed at making Taiwan a developed country in the next six years. This will require technical education to be closely integrated with national aims. Already in place is a centralized educational system with rather rigid specifications for the selection of university students. Taiwan has public and private universities, although the former dominate the picture. The public universities tend to emphasize graduate education more than the private universities. Chang believes the quality of the faculties is good and improving. As evidence of this, he notes that more and more university graduates are staying in Taiwan for graduate studies.

The Taiwanese problems cited by Chang are somewhat reminiscent of those in South Korea. Classes are large but the number of faculty is not adequate. Cooperation between academia and industry is lacking. At universities, the publish-or-perish syndrome is acute and the academic pay structure is poor These problems, Chang says, are slowly being addressed.

Of greater long-term consequence is the character of the students and the curriculum. Chang was one of many speakers who noted the lack of "working ethics" among graduates. He does not mean the absence of inherent honesty but, instead, the tendency to strive for position rather than the production of results.



Several attendees, in private conversations, acknowledged the difficulty of inculcating in students—particularly undergraduates—the idea that one has to constantly produce to justify his or her position.

Attendees noted there is a superficial contradiction here, as Asian students traditionally are noted for the intensity and devotion of their study efforts, an attitude nurtured by parents and society. The problem, apparently, is not that students are unwilling to work. Quite the contrary. But educators are realizing that a substantial change in motivation may be necessary.

A frequently repeated topic was the perceived need for more training in the social sciences and humanities. This has been a subject of great debate among western engineering educators for many years. It has now become a matter of more than academic interest: It is seen as necessary to better fill the needs of international—that is, globalized—commerce.

Probably the most enigmatic of the Pacific Rim countries is China. Only after the death of Mao Zedong was there substantial and demonstrable change in internal access to this nation. The new constitution of 1978 provided a starting point for reform of economics, education, science, and technology. Most information about China's educational organizations date from that time.

Wu Yongshi, president of Tianjin University, notes that, in the 1980s, reforms resulted in an annual GNP growth rate of 9%; growth in national income was 8.7%. Since the national well-being depends on science and technology, much attention has been paid to the training of scientists and engineers. This is reflected in increases in students, faculty, and researchers, as well as in increased funding.

A highly centralized plan has been set up to organize China's educational establishment. The regional distribution of universities tends to follow the centers of population, which are for the most part along the coast.

The distribution of subject matter generally follows the government's perceived needs. Politics, law, finance, and economics are being enhanced, but the study of science and engineering has developed most rapidly. An important event was the issuing of the 1980 regulations of academic degrees in China. These placed special emphasis on graduate degrees. In the 1980s, China produced 6000 doctoral students and 177,000 M.S. students. Two- and three-year junior colleges also have been established to train the requisite mechanics, technicians, and lower level professionals. The numbers of graduate students, undergraduates, and junior college students are adjusted to conform to the prescribed ratio 7:100:56.3.

Procedures for gaining admission to China's various colleges and universities are strictly controlled by

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Education reform in China followed some intense political activity. In 1951–52, China emulated the Soviet Union's educational structure because of the close ties that existed between the two countries. As in the U.S.S.R., Chinese colleges and universities were of three types: comprehensive universities; polytechnic universities; and independent, single-subject universities, such as special universities for the iron and steel industry. Most of the interest with respect to science and technology centers on 14 polytechnic universities administered by the State Education Commission. These are the most prestigious in China and they usually get the bulk of the funding for research and special projects.

When China began sending large numbers of students and exchange professors abroad in the 1980s, they returned with new educational perspectives. For example, they came back realizing that while Chinese students usually had good grounding in the basic sciences, they were often less than well developed in what Wu calls "creative abilities." This perceived lack was considered by some conference attendees as the recognition that endless learning by rote had left no time for cultivation of the imagination. Greater cultivation of creative abilities has now been orchestrated into more recent Chinese curricula.

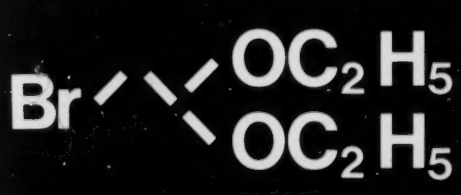
The highly compartmentalized, standardized unit training of the past has been changed to a more diversified curriculum that often takes students "across departments and, occasionally, to other universities." This liberalization of the curriculum sometimes results in graduates obtaining "bi-bachelor degrees."

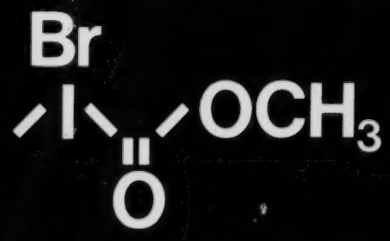
China also has altered the structure of research universities to include new norms. For instance, the allowable percentage of graduate students has been raised to 30% of the total student population. Full professors and associate professors should comprise up to 45% of the entire faculty roster. Allocation of funds to research is set to be at least equal to the funds allocated to teaching.

Reflection on the problems discussed at the conference suggests that the impetus to improve scientific and technical education may be great, but that cultural and social barriers may be greater than imagined.

It is also apparent that the great commercial tide that swept along both the little dragons and the bigger ones in the 1970s and 1980s was largely powered by the indigenous efforts of the people, aided by a favorable international investment climate. A recurring theme in all the presentations was that improvements require more effort and expense than first believed. As one engineer put it, "It's harder to stay in the race than to get into it in the first place." □

Brominated Derivatives





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Facts & Figures for Chemical R&D

Bette Hileman and **Janice R. Long,**
C&EN Washington, and
Ward Worthy, C&EN Chicago

Modest growth in R&D funding in the U.S. is expected in 1991. The National Science Foundation estimates total funding will reach about $152 billion this year, an increase of about $6 billion, or 4%, over 1990 levels. When adjusted for inflation, that represents a 2% gain over the previous year.

Thus, 1991 looks to be a continuation of the pattern of R&D spending of the past five years. Since 1986, overall R&D spending in the U.S. has been rising at an annual rate of somewhat less than 2%, after adjusting for inflation, or 7% for the entire period. This is down sharply from the 5 to 9% annual growth rates R&D spending enjoyed earlier in the decade, when real R&D spending grew 40% from 1980 to 1985.

And even the modest growth expected in 1991 is not being fueled primarily by federal government support of R&D, which, in real terms, is expected to decline 1% this year, to $66 billion. Such growth as is occurring is being financed primarily by industry, which will increase its support from $75 billion in 1990 to $78 billion in 1991, an increase, after adjusting for inflation, of about 2%. Universities and other nonprofit organizations are also doing what they can to offset the federal government's modest increases in R&D support: Universities' contributions to R&D are expected to rise from $4.5 billion in 1990 to $5.0 billion this year, and other nonprofit institutions are raising their support from $2.3 billion to $2.6 billion.

The biggest drop in R&D support comes from the Defense Department, which in 1991 will spend just under $37 billion on R&D, down, even in current dollars, from the $38 billion it spent in 1987. In 1987 32% of total R&D funds were spent on defense-related R&D; this year defense's share has dropped to 26%. Since most defense R&D is for development work, it's not surprising that this portion of total R&D has also declined. It received 63% of total R&D funds in 1987 but this year will account for only 61%. Basic research has picked up most of the balance, rising from 14% of total R&D spending in 1987 to 16% in 1991.

Like R&D spending itself, the fraction of gross national product spent on R&D in the U.S. rose steadily in the early 1980s but has now leveled off. Since 1985, it has been holding fairly steady at 2.7 to 2.8% of the value of all goods and

1 Overview

Where R&D funds come from and where they go. Who gets U.S. chemical patents and in what fields chemistry papers are published . . . . . **Page 37**

2 Federal Government

Spending for R&D by the government as a whole and by various federal agencies, particularly in chemistry and chemical engineering. How funds are divided up among basic, applied, and developmental research . . . . **Page 43**

3 Industry

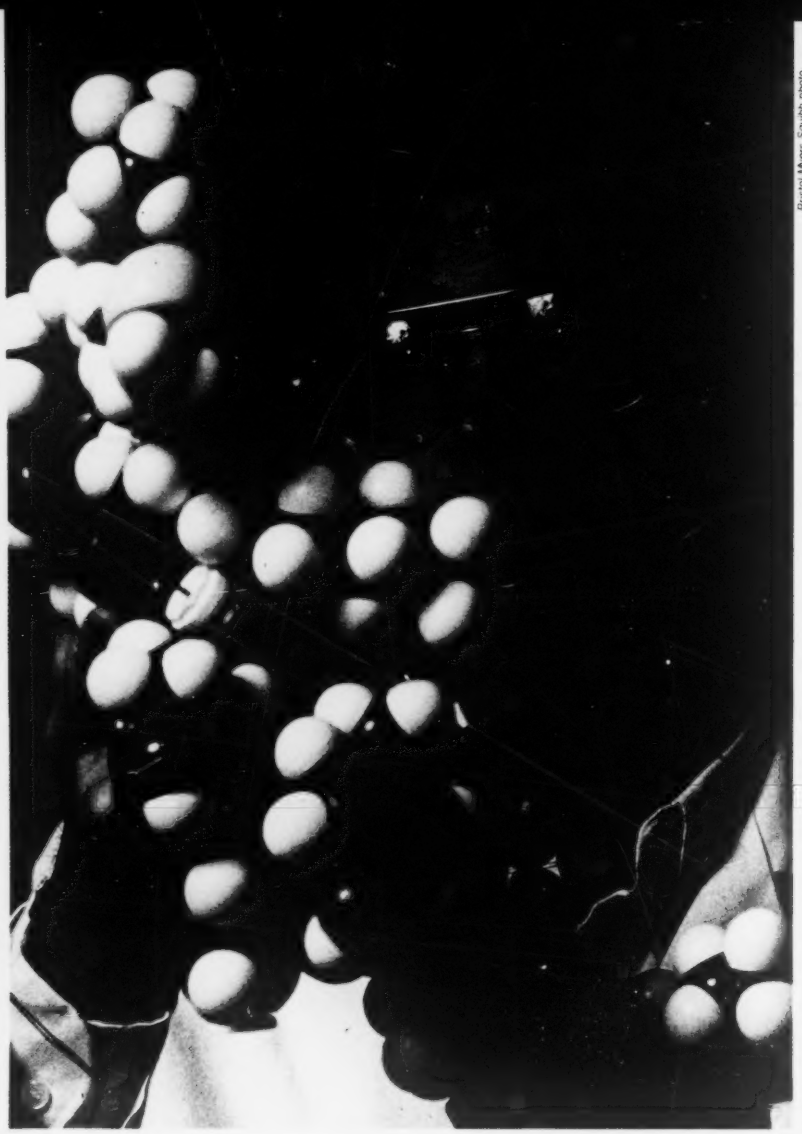
How much industry, especially the chemical industry, spends on R&D. Which industries hire chemists and which ones pay best. . . . . . **Page 53**

4 Universities & Colleges

Who funds academic R&D and which schools do the most. Who spends the most for chemistry and chemical engineering. Trends in equipment purchases, capital spending, and degrees awarded . . . . . **Page 59**

5 International

R&D spending in the U.S. compared with other nations, especially Japan and Western European countries. Which countries publish most of the chemical literature . . . . . **Page 69**



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services produced in the U.S. The share of GNP used for nondefense R&D has remained at 1.9 to 2.0% since 1983.

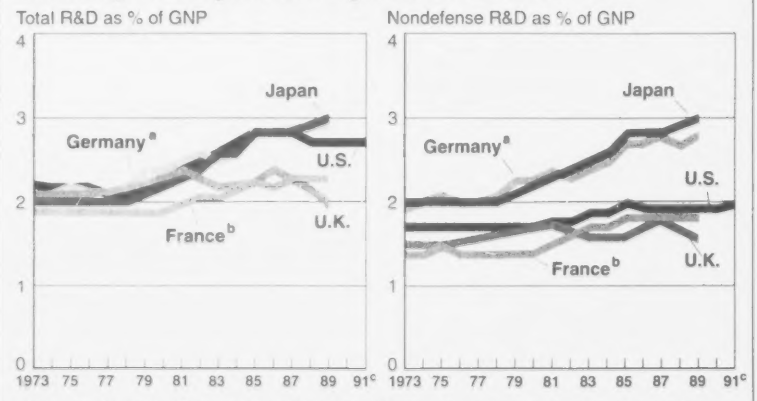
Share of GNP devoted to R&D is a useful measure for comparing R&D efforts in different countries, since it takes into account the relative economic base of different countries. By this measure, both Japan, at 3.0% of GNP, and what was then West Germany, at 2.9%, spent larger fractions of their economic resources on R&D than did the U.S. in 1989, the most recent year for which comparative data are available. However, in that year France, at 2.3%, spent considerably less than the U.S.

When only defense R&D is considered, the differences between countries are even greater. In 1989 Japan spent only 1% of its total R&D on defense, and West Germany spent 5%. These levels contrast greatly with the 21% spent by France and the U.K. on defense, and the 29% used by the U.S.

In absolute terms, the U.S. R&D effort dwarfs that of any other country. It spends 2.4 times as much as its closest competitor—Japan—and five times as much as Germany. But R&D programs in Japan and Germany are expanding faster than they are in the U.S. For example, in 1989, Japan's R&D funding grew 9% and West Germany's rose 6% in real terms over funding levels in 1988, while U.S. expenditures rose only 1%.

Japan is catching up to the U.S. in several other ways as well. The share of U.S. chemical patents awarded to Japanese citizens, corporations, and government agencies rose from 13% of the total in 1981 to 21% in 1990, while the share claimed by U.S. citizens and organizations fell 7% over the same period. The U.S. share of chemical literature abstracted by Chemical Abstracts Service has remained steady at about 27% since 1974, but Japan's share has

Nondefense R&D takes virtually all R&D share of GNP in Germany and Japan, leaving little for defense



a Data are for former West Germany. **b** French data are based on gross domestic product, consequently percentages may be slightly overstated. **c** 1990 and 1991 percentages are C&EN estimates. **Source:** National Science Foundation

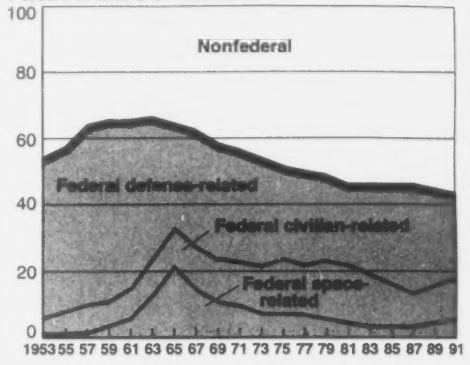
risen from 7.4% in 1974 to 12.1% in 1990. In recent years, the number of scientists and engineers engaged in R&D has also been increasing faster in Japan than in the U.S.

Several other measures reflect the health of the overall R&D effort in the U.S. vis-à-vis the rest of the world. In the U.S., the total number of graduate students in all sciences and engineering has increased at an average rate of 2% a year since 1979, but the number of foreign graduate students without permanent visas has been rising much faster. In 1983, foreign students represented only 26% of the total; in 1989, they were 33%. After graduation, some of these students remain in the U.S., but many return to their native countries.

In chemistry and chemical engineering, these trends are even more striking. In chemistry, foreign graduate students escalated from 23% of the total in 1983 to 35% in 1989, and in chemical engineering from 38% to 49% over the same period.

Funding for research in chemistry at universities has risen at a fairly constant rate of about 11% annually during the past decade, matching the annual rate by which overall R&D funding increased at universities. Funding for R&D in chemical engineering has been rising 12% per year since 1980. The federal government provides most of these funds. In 1989, it supplied $424 million, or 70%, of the $610 million spent by universities on chemical research.

Defense share of U.S. R&D funds has generally declined since 1963



Note: Total R&D funds for 1991 = $152 billion.
Source: National Science Foundation

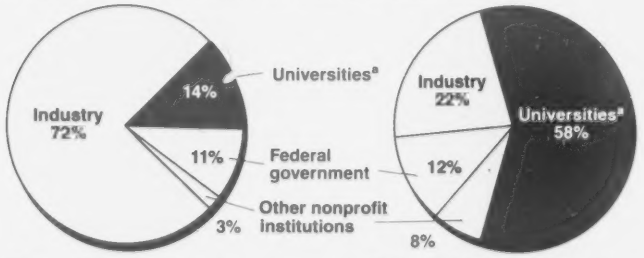
According to NSF, the federal government will spend $832 million for research in chemistry in all sectors in the fiscal year that ends Sept. 30, down 1% from the $839 million it spent in fiscal 1990. Four agencies provide most of these funds—the Department of Energy 23%, NSF 18%, DOD 17%, and Health & Human Services 15%. At universities, NSF, HHS, and DOD together provide 83% of total federal funds for chemical research.

In fiscal-year 1992, total government funding for R&D is expected to grow at a fairly healthy pace. Congressional appropriations call for an 18% boost in NSF's research budget, to $2.64 billion, and a 13% increase for DOE, to $6.16 billion. Chemical research is likely to benefit from these hikes because both agencies are large supporters of such research.

In industry, the chemicals and allied products industry, not surprisingly, is the chief supporter of chemical R&D. In 1990, it spent an estimated $12.6 billion for R&D, 11% more than in 1989. Roughly three quarters of these funds support research in chemical R&D. Drug companies increased their R&D spending 13% to an estimated $6.1 billion. By contrast, overall industrial R&D increased only about 3%.

Much of the information for this Special Report is taken from statistical studies by NSF's Division of Science Resources Studies. These studies are available from the National Science Foundation, Division of Science Resources Studies, Office of the Director, 1800 G St., N.W., Washington, D.C. 20402, phone (202) 634-4634. □

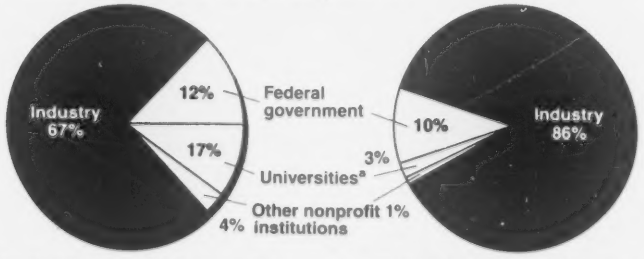
Universities perform only 14% of total R&D even though they do 58% of basic research . . .



Estimated 1991 total R&D spending = $152 billion

Estimated 1991 basic research spending = $24 billion

. . . industry does 67% of applied research and performs all but 14% of development



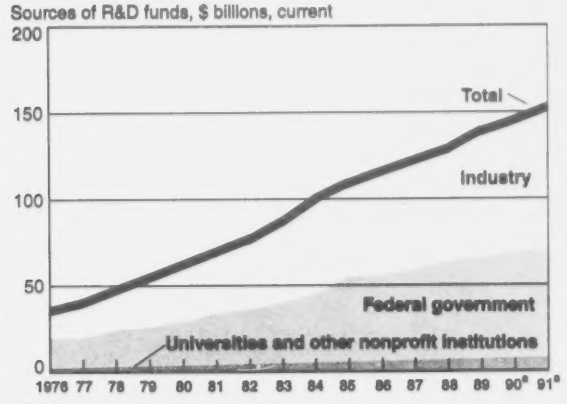
Estimated 1991 applied research spending = $35 billion

Estimated 1991 development spending = $93 billion

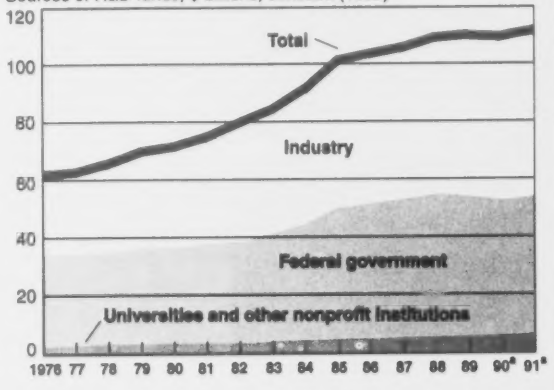
a Includes associated federally funded R&D centers. **Source:** National Science Foundation

Funding Continues To Grow at a Slow Pace

Overall R&D outlays exceed $150 billion in 1991 . . .



. . . but they have barely kept up with inflation since 1986



a Preliminary. Source: National Science Foundation

SOURCES OF R&D FUNDS: Industry contributes more than half, universities' share rises sharply

$ Billions, current	1991a	1990a	1989	1988	1987	1986	1985	1984	1983	1982	1981	Annual change 1990–91	Annual change 1981–91
Industry	$ 78.1	$ 74.7	$ 71.8	$ 67.0	$ 62.6	$ 61.1	$ 58.0	$ 52.2	$ 45.8	$ 40.7	$ 35.9	5%	8%
Federal government	66.0	64.0	62.7	61.5	57.9	54.3	52.1	45.6	40.8	36.6	33.4	3	7
Universities and colleges	5.0	4.5	3.9	3.5	3.2	2.8	2.4	2.1	1.9	1.7	1.6	11	12
Other nonprofit institutions	2.6	2.3	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.0	1.0	13	10
TOTAL	$151.6	$145.5	$140.5	$133.7	$125.4	$119.5	$113.8	$101.1	$ 89.1	$ 80.0	$ 71.9	4%	8%
ANNUAL CHANGE	4%	4%	5%	7%	5%	5%	13%	13%	11%	11%	15%		
$ Billions, constant 1982													
Industry	$ 57.9	$ 56.8	$ 56.8	$ 55.2	$ 53.3	$ 53.6	$ 52.3	$ 48.5	$ 43.6	$ 40.7	$ 38.3	2%	4%
Federal government	49.0	48.7	49.6	50.6	49.2	47.6	46.9	42.3	39.3	36.6	35.7	−1	3
Universities and colleges	3.7	3.4	3.1	2.9	2.7	2.4	2.1	1.9	1.8	1.7	1.7	9	8
Other nonprofit institutions	1.9	1.7	1.6	1.5	1.4	1.2	1.2	1.1	1.1	1.0	1.0	10	6
TOTAL	$112.5	$110.6	$111.1	$110.2	$106.6	$104.9	$102.5	$ 93.8	$ 85.8	$ 80.0	$ 76.6	2%	4%
ANNUAL CHANGE	2%	−1%	1%	3%	2%	2%	9%	9%	7%	4%	5%		

Note: Constant-dollar values are calculated by C&EN from NSF data. Totals do not add up because of rounding. a Preliminary figures, NSF estimates. **Source:** National Science Foundation

PERFORMERS OF R&D: Government's share of total R&D falls in real terms

$ Billions, current	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	1983	1982	1981	Annual change 1990–91	Annual change 1981–91
Industry	$108.4	$104.2	$101.6	$ 97.8	$ 92.2	$ 87.8	$ 84.2	$ 74.8	$65.3	$58.7	$51.8	4%	8%
Federal government	16.4	16.1	15.1	14.3	13.4	13.5	12.9	11.6	10.6	9.1	8.4	2	7
Universities and colleges	17.2	16.0	15.0	13.5	12.2	10.9	9.7	8.6	7.9	7.3	6.6	8	10
University-associated FFRDCs[b]	4.9	4.8	4.7	4.5	4.2	3.9	3.5	3.2	2.7	2.5	2.5	1	7
Other nonprofit institutions	4.7	4.4	4.1	3.6	3.4	3.4	3.4	3.0	2.7	2.4	2.3	8	7
TOTAL	$151.6	$145.5	$140.5	$133.7	$125.4	$119.5	$113.8	$101.1	$89.1	$80.3	$71.9	4%	8%
$ Billions, constant 1982													
Industry	$ 80.4	$ 79.2	$ 80.4	$ 80.6	$ 78.5	$ 77.2	$ 75.9	$ 69.4	$62.8	$58.7	$55.1	1%	4%
Federal government	12.2	12.2	11.9	11.7	11.4	11.8	11.6	10.7	10.2	9.1	9.0	−1	3
Universities and colleges	12.8	12.2	11.8	11.1	10.3	9.5	8.7	8.0	7.6	7.3	7.3	5	6
University-associated FFRDCs[b]	3.6	3.7	3.7	3.7	3.6	3.4	3.2	2.9	2.6	2.5	2.7	−1	3
Other nonprofit institutions	3.5	3.3	3.2	2.9	2.9	2.9	3.1	2.8	2.6	2.4	2.4	5	4
TOTAL	$112.5	$110.6	$111.1	$110.2	$106.8	$104.9	$102.5	$ 93.8	$85.8	$80.0	$76.6	2%	4%

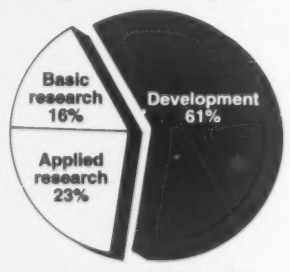
Note: Constant-dollar values are calculated by C&EN based on NSF data. Totals do not add up because of rounding. a Preliminary figures, NSF estimates. b Federally funded R&D centers. **Source:** National Science Foundation

U.S. CHEMICAL PATENTS: Total dropped 4% last year, those of U.S. origin fell 6%

Number of patents issued	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	Total 1981–90
U.S. origin	12,998	13,786	11,247	11,394	10,500	11,531	11,501	10,554	10,613	12,687	116,809
to U.S. corporations	11,214	12,032	9,849	9,897	9,191	10,172	10,117	9,143	9,172	10,973	101,760
to U.S. government	310	295	260	325	290	322	376	330	311	364	3,183
to individuals in the U.S.	1,296	1,297	1,014	1,046	925	986	933	985	1,029	1,276	10,787
to foreign-owned corporations in the U.S.	176	162	124	126	94	51	75	96	101	74	1,079
Foreign origin	12,762	13,139	10,544	10,257	9,110	9,695	8,997	8,085	8,017	9,619	100,205
to U.S.-owned corporations abroad	1,095	1,130	854	847	756	883	833	701	730	896	8,725
to foreign corporations	10,789	11,105	8,936	8,657	7,677	8,085	7,443	6,710	6,517	7,855	83,774
to foreign governments	151	176	170	200	148	161	166	133	165	100	1,570
to foreign individuals	727	728	584	553	529	566	555	521	605	768	6,136
TOTAL	25,758	26,925	21,791	21,651	19,610	21,226	20,498	18,639	18,630	22,306	217,014
% FOREIGN	49.5%	48.8%	48.4%	47.4%	46.5%	45.7%	43.8%	43.3%	43.0%	43.1%	46.2%

Note: Includes patents issued in those technology subclasses that the U.S. Patent & Trademark Office classifies as chemical. **Source:** U.S. Patent & Trademark Office

More than 60% of R&D funds go to development



Estimated total 1991 R&D spending = $152 billion

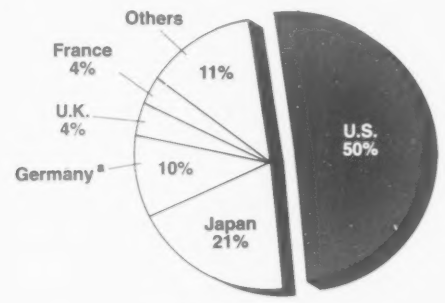
Source: National Science Foundation

RECIPIENTS OF U.S. CHEMICAL PATENTS: Japan claims a steadily growing share

% of patents	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	Total 1981–90
U.S. origin	50%	51%	52%	53%	54%	54%	56%	57%	57%	57%	54%
Foreign origin	50	49	48	47	46	46	44	43	43	43	46
Japan	21	20	20	19	19	18	16	15	14	13	18
Germany[a]	10	10	11	10	10	10	10	11	11	11	11
U.K.	4	4	4	4	4	4	4	4	4	4	4
France	4	3	4	4	3	3	3	3	4	4	4
Switzerland	2	2	2	2	2	2	2	2	2	2	2
Canada	2	2	2	1	1	2	1	1	1	1	1
Italy	2	2	1	1	1	1	1	1	1	1	1
Netherlands	1	1	1	1	1	1	1	1	1	1	1
Sweden	1	1	1	1	1	1	1	1	1	1	1
Belgium	1	1	1	1	1	1	1	1	1	1	1
U.S.S.R.	—	—	—	—	—	—	—	—	—	1	—

Note: Includes patents issued in those technology subclasses that the U.S. Patent & Trademark Office classifies as chemical. a Patents prior to October 1990 were issued to West Germany. **Source:** U.S. Patent & Trademark Office

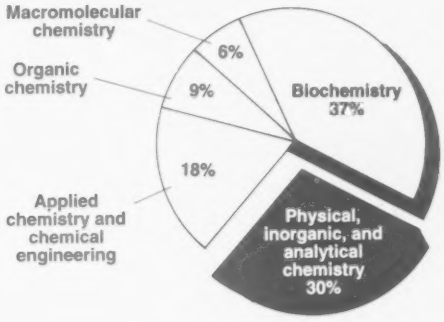
Only half of U.S. chemical patents originate in the U.S.



1990 total U.S. chemical patents issued = 25,758

a Before October 1990 these patents were issued to West Germany.
Source: U.S. Patent & Trademark Office

Nearly one third of chemistry papers are in physical, inorganic, and analytical



1990 total[a] = 394,945

a Number of abstracts of papers published in *Chemical Abstracts*.
Source: Chemical Abstracts Service

PATENT ACTIVITY OF U.S. COMPANIES: Most drug firms were granted fewer patents last year

Number of patents issued	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	Total 1981–90
CHEMICAL COMPANIES											
Du Pont[a]	533	495	437	449	371	395	416	387	331	430	4,244
Dow Chemical	400	431	421	469	371	335	328	246	277	260	3,538
Ciba-Geigy	409	346	279	286	244	305	290	244	281	345	3,029
Union Carbide	43	132	141	159	208	242	231	182	202	262	1,802
American Cyanamid	136	114	101	107	92	115	111	128	129	188	1,221
PPG Industries	100	112	118	118	124	128	137	137	177	189	1,340
Dow Corning	122	105	82	58	68	55	52	37	35	50	664
Ethyl	108	87	51	48	77	105	76	44	31	43	670
Air Products	98	119	70	85	61	80	60	49	54	32	708
Monsanto	84	87	76	91	110	100	138	136	131	211	1,164
Olin	74	80	59	58	81	117	112	85	80	80	826
W. R. Grace	105	111	61	44	43	45	57	52	49	68	635
Hercules	35	46	32	50	43	41	39	37	30	52	405
Rohm & Haas	32	32	18	22	33	31	37	55	49	77	386
International Flavors & Fragrances	40	31	24	38	76	104	95	87	87	96	678
GAF	—	50	23	15	12	23	19	21	32	47	242
TOTAL[b]	2319	2378	1993	2097	2014	2221	2198	1927	1975	2430	21,552
ANNUAL CHANGE	−2%	19%	−5%	4%	−9%	1%	14%	−2%	−19%	10%	
DRUG COMPANIES											
Merck	134	173	125	123	103	105	135	115	135	160	1,307
Warner-Lambert	108	117	113	118	101	73	49	34	25	37	775
Pfizer	82	79	63	67	72	72	89	61	72	92	749
Hoffmann-LaRoche	78	93	59	86	84	74	78	90	118	124	884
Eli Lilly	73	75	68	85	82	107	80	74	104	112	860
American Home Products	66	78	69	46	38	49	32	24	43	52	497
Abbott Laboratories	64	39	39	30	29	36	32	32	50	64	415
Squibb	61	66	74	75	70	74	53	37	56	62	628
SmithKline Beckman	29	62	56	54	27	43	68	59	66	59	523
Upjohn	25	30	15	26	66	66	107	73	122	337	867
TOTAL[b]	720	812	681	710	672	699	723	598	791	1099	7,505
ANNUAL CHANGE	−11%	19%	−4%	6%	−4%	−3%	21%	−24%	−28%	11%	

Note: Includes U.S. chemical and drug companies and U.S. subsidiaries of foreign companies that have received more than 1000 U.S. patents since 1962. a Includes patents issued to Conoco, acquired in 1981, for all years. b These totals include patents issued to companies in this table only. **Source:** U.S. Patent & Trademark Office

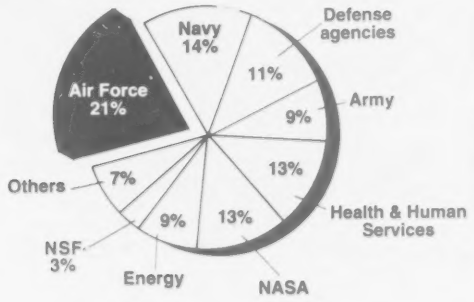
ABSTRACTS OF PAPERS IN *CHEMICAL ABSTRACTS*: Biochemistry's dominant share declining

	1990	1989	1988	1987	1986	1985	1984	1983	1980	Change 1980–90
BIOCHEMISTRY	36.9%	39.2%	39.7%	40.5%	40.4%	40.5%	40.5%	38.3%	39.8%	−2.9%
% of all biochemistry abstracts										
Pharmacology	11.7	12.6	12.7	12.6	12.2	12.3	11.6	11.8	12.0	−0.3
Mammalian hormones[a]	11.5	12.0	12.0	12.2	12.5	12.3	12.4	12.9	6.0	5.5
Mammalian biochemistry[a]	10.5	10.7	10.8	11.1	10.8	11.1	11.3	11.1	16.3	−5.8
Biochemical genetics[b]	10.1	7.9	7.6	6.7	6.1	5.2	4.2	3.8	—	—
Immunochemistry	6.8	6.3	5.8	5.8	6.1	5.3	4.8	4.2	3.1	3.7
Toxicology	6.7	7.8	7.9	8.3	7.8	7.9	8.0	8.5	8.3	−1.6
Enzymes	6.1	6.1	6.1	5.4	5.6	5.6	5.8	6.1	6.2	−0.1
Microbial biochemistry[a]	5.4	5.1	4.8	5.1	5.7	5.7	5.2	5.1	5.2	0.2
General biochemistry	5.2	5.1	5.3	4.6	4.7	4.9	5.3	5.8	6.6	−1.4
Plant biochemistry[a]	5.1	4.6	5.0	5.3	5.2	5.5	6.2	5.9	5.7	−0.6
Biochemical methods	4.7	5.1	5.1	4.8	5.0	4.9	4.9	4.9	5.5	−0.8
Others	16.2	16.7	16.9	18.1	18.3	19.3	20.3	19.9	25.1	−8.9
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
PHYSICAL, INORGANIC, AND ANALYTICAL CHEMISTRY	30.3%	29.0%	28.8%	29.0%	29.8%	29.8%	28.8%	29.6%	28.6%	1.7%
% of all physical, inorganic, and analytical chemistry abstracts										
Nuclear chemistry	17.1	19.4	17.8	19.5	19.9	21.8	22.2	22.5	23.2	−6.1
Spectra	16.9	18.1	20.0	20.4	20.0	18.4	18.0	17.6	18.2	−1.3
Electric phenomena	13.2	13.9	12.5	10.9	10.8	10.8	10.8	10.0	11.2	2.0
Analytical chemistry	7.9	5.1	5.7	5.9	6.8	6.1	6.3	6.2	5.6	2.3
General physical chemistry	7.7	6.9	7.2	7.9	7.0	6.9	6.9	7.3	7.1	0.6
Crystallography and liquid crystals	7.3	7.8	7.0	7.1	7.0	7.5	7.8	8.3	8.1	−0.8
Others	29.9	25.8	29.8	28.3	28.5	28.5	28.0	28.1	26.6	3.3
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
APPLIED CHEMISTRY AND CHEMICAL ENGINEERING	18.2%	18.1%	18.6%	18.0%	18.2%	18.4%	17.6%	19.4%	18.9%	−0.7%
% of all applied chemistry and chemical engineering abstracts										
Metals and alloys	24.5	22.1	21.7	20.6	20.8	20.0	18.9	19.1	22.0	2.5
Water, wastes, and pollution	18.8	17.8	20.4	20.4	21.9	20.2	21.0	19.6	22.5	−3.7
Ceramics	9.4	9.1	6.7	6.3	5.8	5.6	5.1	5.4	4.1	5.3
Unit operations and processes	9.2	10.3	8.0	9.0	7.1	7.5	7.0	7.5	6.0	3.2
Pharmaceuticals and pharmaceutical analysis	8.2	7.8	7.6	7.8	8.2	8.0	7.0	6.5	5.5	2.7
Fossil fuels, derivatives, and related products	8.0	8.7	8.8	9.6	9.0	10.1	10.1	10.3	8.9	−0.9
Mineralogical and geological chemistry	7.8	9.3	11.8	11.2	12.0	12.5	14.6	14.1	15.7	−7.9
Others	14.1	14.9	15.0	15.1	15.2	16.1	16.3	17.5	15.3	−1.2
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
ORGANIC CHEMISTRY	8.7%	7.8%	7.3%	6.9%	5.9%	6.4%	7.6%	7.3%	7.4%	1.3%
% of all organic chemistry abstracts										
Physical organic chemistry	21.2	25.9	23.0	23.9	27.3	30.6	32.0	30.5	38.8	−17.6
Organometallic and organometalloidal compounds	20.4	18.4	15.7	16.1	18.3	16.2	17.1	16.3	8.2	12.2
Heterocyclic compounds[a]	17.4	16.1	18.8	19.9	15.0	16.1	15.6	16.2	17.3	0.1
Carbohydrates	7.4	6.5	8.1	5.6	7.8	5.7	5.7	5.8	5.7	1.7
Aromatic compounds[a]	7.1	6.9	7.2	7.7	7.3	6.3	6.3	7.1	7.8	−0.7
Amino acids, peptides, and proteins[a]	6.0	4.5	5.8	4.3	3.9	4.6	4.8	4.5	3.7	2.3
Biomolecules and their synthetic analogs[b]	5.9	5.8	6.1	5.8	5.0	4.9	4.4	4.5	—	—
Aliphatic compounds[a]	3.3	3.6	4.1	4.9	4.4	4.2	3.6	4.3	6.0	−2.7
Others	11.3	12.3	11.2	11.8	11.0	11.4	10.5	10.8	12.5	−1.2
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—
MACROMOLECULAR CHEMISTRY	5.9%	5.9%	5.6%	5.6%	5.7%	4.9%	5.5%	5.4%	5.3%	0.6%
% of all macromolecular chemistry abstracts										
Synthetic high polymers	38.6	34.4	34.8	35.2	34.1	34.1	34.0	34.4	27.0	11.6
Plastics manufacture and uses	23.3	25.1	23.7	23.6	23.8	25.3	24.2	24.4	28.1	−4.8
Industrial organic chemicals, leather, fats, and waxes	8.4	8.1	6.8	5.6	4.6	4.4	4.8	4.8	—	—
Cellulose, lignin, paper, and other wood products	7.6	9.2	9.6	8.8	9.8	9.1	9.6	9.1	10.9	−3.3
Textiles	6.7	7.2	7.3	8.1	8.8	8.2	7.3	7.9	10.1	−3.4
Coatings, inks, and related products	5.2	5.6	5.7	5.8	7.2	7.2	7.8	6.6	7.4	−2.2
Synthetic elastomers and natural rubber	4.8	5.6	6.7	7.2	6.7	6.8	7.3	7.5	8.4	−3.6
Others	5.4	4.8	5.4	5.7	5.0	4.9	5.0	5.3	7.9	−2.5
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	—

How to read this table: Using biochemistry as an example, in 1990 36.9% of all the papers abstracted by Chemical Abstracts Service are in the various subdisciplines of biochemistry; 11.7% of all abstracts in biochemistry, in turn, are in the subdiscipline of pharmacology, and so on. a Definition of section changed in 1982. b New section in 1982. **Source:** Chemical Abstracts Service

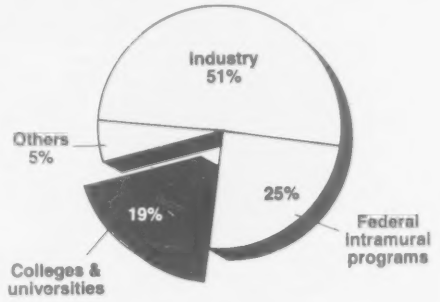
Defense Funding Still Large, but Shrinking

A fifth of federal R&D funds comes from the Air Force . . .



Estimated fiscal 1991 total federal R&D obligations = $66.1 billion

. . . and about a fifth of federal R&D is performed by academia



Estimated fiscal 1991 total federal R&D obligations = $66.1 billion

Source: National Science Foundation

FEDERAL OBLIGATIONS FOR R&D: Growth in civilian R&D programs outpacing defense

$ Millions	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
Defense	$36,918	$35,899	$37,577	$35,415	$35,232	$32,938	$29,792	$25,373	3%	6%
Air Force	13,583	13,720	15,237	15,034	15,348	13,594	13,261	12,092	−1	2
Navy	9,358	9,589	9,666	9,514	9,508	9,650	9,127	7,606	−2	3
Army	6,228	5,593	5,659	4,806	5,020	4,809	4,571	4,226	11	7
Defense agencies	7,348	6,744	6,859	5,833	5,220	4,767	2,782	1,392	9	27
Health & Human Services	8,686	8,457	7,903	7,158	6,809	5,658	5,451	4,831	5	9
National Institutes of Health	7,473	7,141	6,778	6,291	5,853	5,005	4,828	4,257	5	8
Alcohol, Drug Abuse & Mental Health Administration	920	821	696	555	476	396	378	337	12	15
NASA	8,322	8,635	5,394	4,330	3,787	3,420	3,327	2,822	25	17
Energy	6,006	5,698	5,193	5,036	4,757	4,688	4,996	4,674	5	4
NSF	1,983	1,766	1,670	1,532	1,471	1,353	1,346	1,203	12	7
Agriculture	1,158	1,104	1,036	1,017	948	929	943	866	5	4
Agricultural Research Service	588	547	524	505	479	463	470	451	7	4
Cooperative State Research Service	335	325	307	298	271	269	284	236	3	5
Forest Service	149	153	131	136	127	113	113	108	−3	6
EPA	442	417	380	347	348	317	320	261	6	8
Interior	489	504	469	417	404	385	392	411	−3	2
Geological Survey	305	300	278	235	227	219	215	209	2	6
Commerce	426	424	398	389	402	399	399	358	0	3
National Oceanic & Atmospheric Administration	268	277	269	263	286	275	270	244	−3	1
National Institute of Standards & Technology	145	133	116	108	99	101	101	96	9	6
Others	1,475	1,416	1,384	1,186	1,298	1,325	1,367	1,427	2	0
TOTAL	$66,107	$62,320	$61,406	$56,935	$55,255	$51,412	$48,332	$42,225	6%	7%
ANNUAL CHANGE	1%	6%	8%	3%	7%	6%	14%	9%		

Note: Fiscal years. a Estimated. Source: National Science Foundation

PERFORMERS OF FEDERALLY FUNDED R&D: Industry's growing share tops 50% of total

Federal obligations, $ millions	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91[a]	Annual change 1984–91
Industry	**$33,574**	**$30,908**	**$30,508**	**$28,630**	**$26,628**	**$25,898**	**$23,496**	**$20,219**	**9%**	**8%**
FFRDCs[b] administered by industry	2,062	2,054	1,960	1,911	1,860	1,697	1,791	1,608	0	4
Federal intramural Programs	**16,396**	**16,094**	**15,121**	**14,115**	**13,413**	**13,535**	**12,945**	**11,572**	**2**	**5**
Universities and colleges	**12,845**	**12,158**	**12,169**	**11,302**	**10,545**	**9,327**	**9,156**	**8,033**	**8**	**7**
FFRDCs[b] administered by universities	3,654	3,410	3,497	3,474	3,210	2,768	2,816	2,486	7	6
Nonprofit institutions	**2,784**	**2,629**	**2,521**	**2,186**	**2,221**	**2,228**	**2,388**	**2,094**	**6**	**4**
FFRDCs[b] administered by nonprofit institutions	482	445	522	506	511	551	689	597	8	−4
Foreign	**325**	**357**	**919**	**392**	**295**	**296**	**245**	**176**	**−9**	**9**
State and local governments	**184**	**175**	**167**	**142**	**148**	**128**	**129**	**131**	**5**	**5**
TOTAL	**$66,108**	**$62,321**	**$61,406**	**$56,769**	**$55,253**	**$51,412**	**$48,360**	**$42,225**	**6%**	**7%**
ANNUAL CHANGE	**6%**	**1%**	**8%**	**3%**	**7%**	**6%**	**15%**	**16%**		

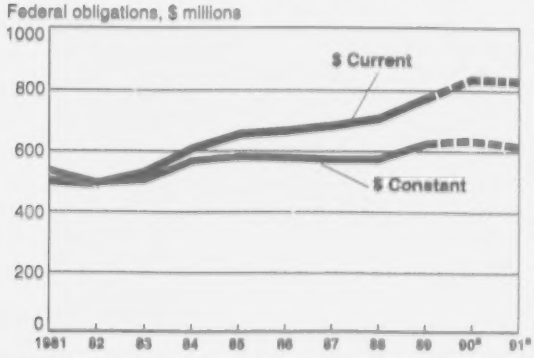
Note: Fiscal years. a Estimated. b Federally funded R&D centers. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR SCIENTIFIC DISCIPLINES: Chemistry lags most other fields

$ Millions for research only	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1989–91
Life sciences	**$ 9,407**	**$ 8,914**	**$ 8,495**	**$ 7,724**	**$ 7,344**	**$ 6,464**	**$ 6,366**	**$ 5,836**	**6%**	**8%**
Engineering	**4,684**	**4,361**	**4,442**	**3,956**	**3,906**	**3,739**	**3,629**	**3,624**	**7**	**4**
National engineering centers	790	814	784	678	669	632	664	858	−3	−1
Metallurgy and materials	599	520	521	457	362	445	439	341	15	8
Chemical	250	235	230	258	216	246	254	145	6	8
Physical sciences	**4,191**	**3,894**	**3,705**	**3,317**	**3,253**	**3,089**	**3,044**	**2,969**	**8**	**5**
Physics	2,479	2,287	2,191	1,975	1,854	1,806	1,820	1,836	8	4
Chemistry	832	839	782	703	680	662	645	606	−1	5
Environmental sciences	**2,345**	**2,104**	**1,773**	**1,607**	**1,512**	**1,482**	**1,404**	**1,276**	**11**	**9**
Mathematical and computer sciences	**792**	**721**	**735**	**643**	**641**	**615**	**578**	**440**	**10**	**9**
Other sciences	**1,801**	**1,689**	**1,671**	**1,402**	**1,288**	**1,133**	**1,110**	**1,034**	**7**	**8**
TOTAL	**$23,220**	**$21,683**	**$20,765**	**$18,649**	**$17,943**	**$16,502**	**$16,130**	**$14,979**	**7%**	**6%**
ANNUAL CHANGE	**7%**	**4%**	**11%**	**4%**	**9%**	**2%**	**8%**	**5%**		

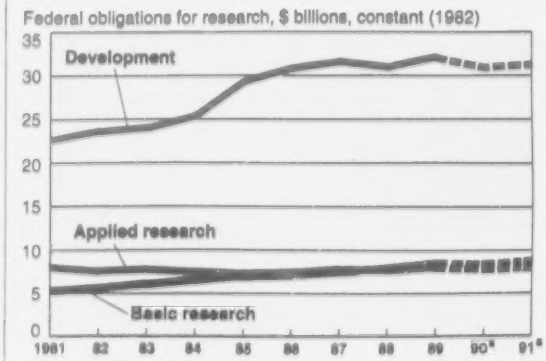
Note: Fiscal years. a Estimated. **Source:** National Science Foundation

Real support for chemical research rose less than 2% per year over past decade



Note: Fiscal years. Constant-dollar (1982) values calculated by C&EN from NSF data. a Estimated. **Source:** National Science Foundation

Funding for basic research continues to climb, other areas have leveled off



Note: Fiscal years. Constant-dollar values calculated by C&EN from NSF data. a Estimated. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR BASIC RESEARCH: Growth averaging 8% per year

$ Millions	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
Health & Human Services	$ 4,940	$ 4,662	$ 4,388	$4081	$3830	$3339	$3233	$2815	6%	8%
National Institutes of Health	4,501	4,257	4,053	3795	3577	3119	3018	2625	6	8
Alcohol, Drug Abuse & Mental Health Administration	398	357	308	266	232	203	197	171	11	13
NSF	1,853	1,651	1,563	1433	1371	1275	1262	1132	6	7
NASA	1,803	1,656	1,417	1113	1014	917	751	755	9	13
Energy	1,677	1,531	1,411	1185	1069	960	943	830	9	11
Defense	972	892	948	877	908	924	861	848	9	2
Navy	396	354	354	342	354	337	343	316	13	3
Air Force	201	177	203	196	222	216	198	192	14	1
Army	191	177	187	166	217	248	241	222	8	−2
Defense agencies	181	184	204	173	115	122	79	118	−2	6
Agriculture	547	515	485	481	446	433	445	393	7	5
Agricultural Research Service	317	295	283	271	253	248	250	241	7	4
Cooperative State Research Service	163	154	143	146	133	132	142	100	9	7
Forest Service	56	58	50	52	49	42	44	41	−5	5
Interior	191	200	189	126	135	133	138	126	−4	6
Geological Survey	153	153	140	90	85	83	81	79	0	10
Bureau of Mines	32	43	44	32	46	45	50	41	−26	−4
EPA	98	78	51	27	31	39	39	30	30	18
Commerce	33	30	29	31	26	27	23	21	10	7
National Institute of Standards & Technology	32	29	28	26	25	26	22	20	10	7
Others	141	134	121	120	116	107	124	119	5	9
TOTAL	$12,255	$11,348	$10,602	$9474	$8944	$8153	$7819	$7067	8%	8%
ANNUAL CHANGE	8%	7%	12%	6%	10%	4%	11%	13%		

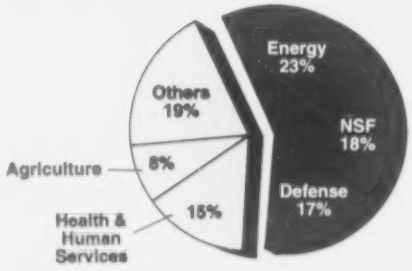
Note: Fiscal years. a Estimated. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR APPLIED RESEARCH: Funds for NASA growing rapidly

$ Millions	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
Health & Human Services	$ 3,037	$ 2,915	$ 2,700	$2416	$2195	$1851	$1796	$ 1652	4%	9%
National Institutes of Health	2,179	2,117	2,008	1886	1740	1489	1410	1286	3	8
Alcohol, Drug Abuse & Mental Health Administration	516	459	385	287	241	192	180	165	12	18
Defense	2,497	2,343	2,708	2382	2440	2303	2307	2201	7	2
Defense agencies	849	846	1,038	791	751	735	738	717	0	9
Army	604	543	636	588	693	579	583	487	11	3
Air Force	580	529	605	577	563	542	538	548	10	1
Navy	464	425	429	406	432	447	448	450	9	0
NASA	1,970	1,836	1,461	1219	1256	1152	1033	955	20	11
Energy	1,064	1,109	1,021	1051	1029	1081	1198	1195	−4	−2
Agriculture	570	552	517	505	473	484	486	442	3	4
Agricultural Research Service	235	219	209	200	201	188	192	184	7	3
Cooperative State Research Service	172	175	165	153	138	137	143	136	−2	3
Forest Service	88	90	77	80	73	68	66	64	−2	5
Commerce	329	337	322	311	313	313	301	276	−2	3
National Oceanic & Atmospheric Administration	229	240	234	225	234	237	224	198	−5	3
National Institute of Standards & Technology	91	87	78	73	64	63	65	64	5	5
EPA	265	240	223	241	246	179	176	142	10	9
Interior	261	270	253	266	247	235	231	254	−3	0
Geological Survey	135	132	127	136	132	128	130	125	2	1
NSF	130	115	108	100	99	78	84	71	13	9
Others	842	818	840	705	700	693	720	725	3	2
TOTAL	$10,965	$10,335	$10,163	$9176	$8999	$8349	$8312	$ 7911	6%	5%
ANNUAL CHANGE	6%	2%	11%	2%	8%	0%	5%	−1%		

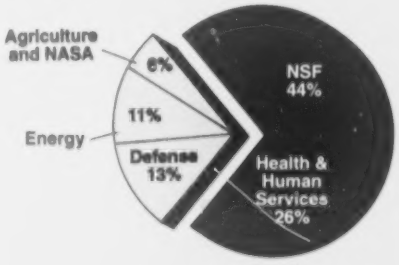
Note: Fiscal years. a Estimated. **Source:** National Science Foundation

Three agencies provide nearly 60% of all chemical research funding . . .



Estimated fiscal 1991 federal chemistry research obligations = $832 million

. . . but NSF and HHS alone provide 70% of the funds for universities



Estimated fiscal 1991 federal chemistry university research obligations = $315 million[a]

Source: National Science Foundation

a Total is for these six agencies only.

UNIVERSITY RESEARCH: Life sciences garner just under 60% of government funds

Federal obligations, $ millions	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
Life sciences	$4682	$4429	$4396	$4029	$3824	$3252	$3192	$2800	5%	8%
Physical sciences	1035	960	930	857	823	752	750	698	8	6
Physics	546	504	486	425	404	405	402	375	8	6
Chemistry	315	298	298	295	281	266	267	242	6	5
Engineering	806	721	749	673	600	609	507	474	12	8
Metallurgy and materials	213	171	194	175	108	133	107	88	25	13
Chemical	48	43	42	57	55	51	46	51	12	−1
Environmental sciences	511	476	460	408	400	366	361	320	8	7
Mathematical and computer sciences	359	354	344	305	289	274	253	182	1	10
Other sciences	640	609	593	494	449	365	348	304	5	11
TOTAL	$8033	$7547	$7472	$6766	$6384	$5617	$5411	$4777	6%	8%
ANNUAL CHANGE	6%	1%	10%	6%	14%	4%	13%	12%		

Note: Fiscal years. Includes funding only from six agencies that together represent approximately 96% of federal research support to universities. a Estimated.
Source: National Science Foundation

UNIVERSITY RESEARCH IN CHEMISTRY: NSF, NIH, and DOD dominate funding

Federal obligations, $ millions	1991[a]	1990[a]	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
NSF	$139.7	$124.5	$118.5	$111.6	$107.1	$103.5	$105.1	$100.7	12%	5%
Health & Human Services	80.5	78.6	78.4	91.4	85.0	75.0	75.2	63.2	5	4
National Institutes of Health	78.1	74.8	74.8	89.3	83.4	74.4	74.7	62.8	5	3
Alcohol, Drug Abuse & Mental Health Administration	2.4	2.0	1.6	2.1	1.6	0.6	0.6	0.4	20	29
Defense	42.1	39.2	42.0	41.3	45.0	43.2	40.4	34.7	7	3
Air Force	16.8	14.9	15.5	17.0	18.4	16.1	14.0	na	13	na
Navy	15.7	14.8	14.3	13.6	17.2	13.9	15.5	na	6	na
Army	6.7	6.7	7.7	8.8	8.3	12.4	10.9	na	0	na
Defense agencies	2.8	2.8	4.4	1.8	1.1	0.9	0	na	0	na
Energy	35.4	39.8	43.7	33.8	28.5	27.8	26.0	26.3	−11	15
Agriculture	11.1	12.1	11.8	11.8	11.2	12.2	15.5	13.5	−8	−3
NASA	5.4	5.9	5.2	4.8	4.3	4.2	4.1	4.1	8	7
TOTAL	$315.2	$298.1	$297.7	$294.7	$281.1	$265.7	$269.4	$242.3	6%	4%
ANNUAL CHANGE	6%	0%	1%	5%	6%	−1%	11%	18%		

Note: Fiscal years. Data from these six agencies represent approximately 96% of federal obligations for 1991. a Estimated. na = not available. Source: National Science Foundation

FEDERAL OBLIGATIONS FOR DEVELOPMENT: Defense Department accounts for 78%

$ Millions	1991*	1990*	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
Defense	**$33,448**	**$32,644**	**$33,921**	**$32,176**	**$31,884**	**$29,711**	**$26,623**	**$22,324**	**2%**	**6%**
Air Force	12,801	13,013	14,430	14,261	14,563	12,835	12,524	11,352	−2	2
Navy	8,494	8,810	8,883	8,766	8,721	8,866	8,336	6,840	−4	3
Defense agencies	6,319	5,713	5,617	4,868	4,354	3,911	1,965	557	11	41
Army	5,433	4,873	4,836	4,052	4,110	3,982	3,747	3,517	11	6
NASA	**4,549**	**3,340**	**2,515**	**1,999**	**1,518**	**1,351**	**1,544**	**1,113**	**36**	**22**
Energy	**3,265**	**3,057**	**2,761**	**2,801**	**2,659**	**2,648**	**2,825**	**2,649**	**7**	**3**
Health & Human Services	**911**	**881**	**814**	**661**	**584**	**468**	**423**	**365**	**3**	**15**
National Institutes of Health	793	725	682	610	536	418	400	347	3	14
Transportation	**261**	**249**	**182**	**213**	**256**	**317**	**358**	**371**	**5**	**−4**
EPA	**80**	**101**	**107**	**80**	**71**	**100**	**106**	**89**	**−20**	**−2**
Commerce	**64**	**56**	**47**	**47**	**64**	**60**	**75**	**62**	**14**	**0**
National Oceanic & Atmospheric Administration	39	37	34	35	52	37	45	47	1	−2
National Institute of Standards & Technology	22	17	10	9	9	12	14	12	29	9
Agriculture	**41**	**38**	**36**	**31**	**29**	**32**	**32**	**31**	**8**	**4**
Agricultural Research Service	35	32	31	26	24	27	28	27	9	4
Interior	**37**	**34**	**26**	**24**	**22**	**17**	**22**	**31**	**9**	**3**
Geological Survey	18	15	13	11	10	7	4	5	20	29
Others	**232**	**237**	**230**	**253**	**226**	**207**	**195**	**212**	**−2**	**1**
TOTAL	**$42,888**	**$40,637**	**$40,640**	**$38,285**	**$37,313**	**$34,910**	**$32,202**	**$27,248**	**6%**	**7%**
ANNUAL CHANGE	**6%**	**8%**	**6%**	**3%**	**7%**	**8%**	**18%**	**11%**		

Note: Fiscal years. a Estimated. **Source:** National Science Foundation

ENGINEERING RESEARCH: Over past five years support for chemical engineering has fallen by an

Federal obligations, $ millions	1991* All engineering	1991* Chemical engineering	1991* Metallurgy & materials	1990* All engineering	1990* Chemical engineering	1990* Metallurgy & materials	1989 All engineering	1989 Chemical engineering	1989 Metallurgy & materials
Defense	**$1747.7**	**$40.9**	**$398.0**	**$1619.1**	**$ 41.6**	**$328.3**	**$1636.1**	**$ 46.6**	**$343.3**
Air Force	463.2	3.3	47.4	409.4	3.3	44.7	480.5	11.6	42.9
Defense agencies	452.2	0	259.3	443.9	0	204.7	565.1	0.2	221.6
Navy	432.6	14.6	61.2	390.2	12.4	55.4	389.9	11.6	56.1
Army	399.7	23.0	28.1	375.6	25.9	23.5	400.6	23.4	22.7
NASA	**1689.1**	**12.3**	**50.2**	**1513.2**	**13.5**	**40.7**	**1446.4**	**6.0**	**36.5**
Energy	**420.0**	**3.0**	**78.4**	**436.2**	**5.5**	**79.8**	**406.1**	**4.5**	**78.0**
NSF	**276.4**	**50.6**	**33.4**	**245.7**	**44.9**	**29.7**	**232.0**	**42.4**	**28.1**
Transportation	**93.3**	**6.9**	**0.3**	**89.5**	**6.3**	**0.3**	**87.6**	**6.9**	**0.2**
Interior	**76.8**	**6.8**	**26.8**	**94.2**	**5.7**	**28.1**	**92.8**	**5.8**	**23.4**
EPA	**71.4**	**28.9**	**0.6**	**62.2**	**23.7**	**0.6**	**52.7**	**19.2**	**0.7**
Commerce	**60.6**	**5.4**	**13.3**	**60.5**	**3.8**	**12.3**	**52.7**	**3.2**	**11.6**
Agriculture	**54.2**	**7.7**	**0**	**36.7**	**7.5**	**0**	**34.5**	**7.2**	**0**
Others	**214.2**	**0**	**0.1**	**203.8**	**0.1**	**0**	**201.1**	**0.2**	**0.2**
TOTAL	**$4683.9**	**$162.1**	**$599.1**	**$4361.1**	**$152.6**	**$519.8**	**$4442.0**	**$142.2**	**$521.0**
ANNUAL CHANGE	**7%**	**6%**	**15%**	**−2%**	**7%**	**0**	**12%**	**−45%**	**14%**

Note: Fiscal years. a Estimated. **Source:** National Science Foundation

FEDERAL OBLIGATIONS FOR CHEMICAL RESEARCH: NSF now second largest source of funds

$ Millions	1991*	1990*	1989	1988	1987	1986	1985	1984	Annual change 1990–91	Annual change 1984–91
Energy	$190.4	$238.4	$213.4	$162.9	$145.5	$145.9	$143.0	$140.4	−20%	4%
NSF	151.2	134.8	127.4	120.6	115.3	112.6	115.6	109.9	12	5
Defense	141.2	131.0	133.5	125.0	144.9	163.4	156.4	139.8	8	0
Army	65.3	64.0	60.4	57.5	72.2	81.4	78.2	66.3	2	−1
Air Force	43.9	38.1	43.2	43.6	43.3	42.0	39.5	36.7	15	3
Navy	29.2	26.1	25.5	22.1	28.4	39.1	38.3	36.6	12	−4
Defense agencies	2.8	2.8	4.4	1.8	1.1	0.9	0.4	0.3	0	38
Health & Human Services	122.7	114.8	107.8	123.8	115.5	104.2	99.1	86.3	7	5
National Institutes of Health	108.9	103.6	98.6	114.4	108.1	99.5	95.1	84.1	5	4
Alcohol, Drug Abuse & Mental Health Administration	13.8	11.2	9.2	9.4	7.4	4.7	4.0	2.3	23	29
Agriculture	54.8	52.9	51.0	60.8	65.0	58.6	58.0	69.0	3	−1
Agricultural Research Service	44.8	41.7	41.2	40.9	46.4	40.0	36.1	51.6	7	−2
Cooperative State Research Service	11.5	12.5	12.3	12.2	11.5	12.4	16.1	13.5	−8	−3
Forest Service	8.5	8.7	7.5	7.6	7.1	6.2	5.7	3.9	−2	12
NASA	52.2	57.9	47.4	27.5	13.4	11.8	16.3	7.3	−10	32
EPA	46.4	37.4	32.5	30.6	34.6	20.1	17.5	15.9	24	16
Commerce	25.5	25.1	24.4	23.6	22.9	19.1	17.7	15.3	2	9
National Institute of Standards & Technology	20.2	18.3	17.7	16.9	16.5	16.4	15.4	14.1	10	5
National Oceanic & Atmospheric Administration	5.3	6.8	6.7	6.7	6.4	2.4	1.4	1.3	−12	26
Interior	25.1	22.7	22.0	21.9	20.9	20.3	19.4	19.2	11	4
Geological Survey	25.0	22.6	21.9	20.8	20.2	19.4	18.4	11	4	
Others	12.9	14.2	13.2	6.4	2.4	6.3	1.5	3.3	−9	22
TOTAL	$832.4	$839.0	$782.6	$703.1	$680.3	$662.4	$644.5	$606.4	1%	5%
ANNUAL CHANGE	−1%	7%	11%	3%	3%	3%	6%	17%		

Note: Fiscal years. a Estimated. **Source:** National Science Foundation

average of 8% a year

1988			1987			1986		
All engineering	Chemical engineering	Metallurgy & materials	All engineering	Chemical engineering	Metallurgy & materials	All engineering	Chemical engineering	Metallurgy & materials
$1636.1	$ 41.9	$294.4	$1629.7	$ 46.9	$203.6	$1505.6	$ 50.3	$253.7
455.1	1.8	43.2	460.3	1.8	34.5	444.7	1.9	33.4
416.8	0.1	174.8	325.6	0	79.8	269.5	0	76.2
379.6	19.8	52.5	401.5	21.3	57.2	397.8	24.4	117.4
384.4	20.3	23.8	442.4	23.8	32.1	373.6	24.0	26.8
1138.2	2.0	18.8	1170.5	1.5	19.9	1066.9	1.0	16.2
479.5	134.5	76.4	442.2	88.9	77.1	494.2	121.6	82.8
206.6	38.9	25.8	191.7	37.3	22.9	199.1	33.4	43.5
71.9	1.0	3.6	48.1	1.0	0.7	52.8	1.9	1.8
85.3	5.1	24.8	87.8	5.0	28.5	93.2	4.7	38.5
50.7	24.2	0.3	55.4	25.6	0.5	48.6	23.9	0.5
49.3	2.7	10.6	41.3	2.4	5.8	41.7	2.6	7.6
31.7	7.7	0	33.9	6.9	0	31.1	6.0	0
206.7	0.1	0.2	206.8	0.3	0.2	205.9	0.4	0.5
$3956.2	$258.1	$456.7	$3906.2	$215.8	$362.0	$3738.9	$245.8	$445.0
1%	20%	26%	4%	−12%	−19%	3%	−3%	1%

Fiscal 1992 is shaping up well for R&D, as Congress slates budget increases for funding agencies

DOD R&D BUDGET: Air Force work accounts for just under 40%

$ Millions	1992 House appropriation	1992 Administration request	1991	1990	1989	% change 1991-92[a]
Air Force	$14,263.9	$15,032.6	$11,961.3	$14,626.9	$14,50[illegible]	19%
Defense agencies	8,979.1	10,238.5	9,115.7	8,399.4	8,427.9	−1
Navy	7,464.9	7,346.6	9,237.9	9,393.6	9,382.3	−20
Army	6,241.6	6,307.3	5,607.4	5,446.5	5,130.2	1
TOTAL	**$36,949.5**	**$38,921.0**	**$35,722.3**	**$37,866.4**	**$37,442.7**	**3%**

Note: Fiscal years. a Based on House appropriation.

DEPARTMENT OF ENERGY: Defense accounts for just 30% of R&D budget

$ Millions	1992 Congressional appropriation	1992 Administration request	1991	1990	1989	% change 1991-92
ENERGY R&D	**$4236.1**	**$4031.2**	**$3717.3**	**$3053.3**	**$2927.4**	**14%**
General science and research	**1472.5**	**1548.9**	**1148.7**	**737.6**	**717.6**	**28**
Basic energy sciences	**764.7**	**714.7**	**711.7**	**582.5**	**552.4**	**7**
Materials sciences	257.1	257.1	274.9	203.2	180.7	−6
Chemical sciences	158.3	158.3	157.6	144.1	135.0	0
Fossil	**450.0[a]**	**227.0**	**458.8**	**416.5**	**380.6**	**−2[b]**
Environment	**353.3**	**312.6**	**393.9**	**314.0**	**259.0**	**−10**
Fusion	**337.1**	**337.1**	**273.6**	**323.0**	**351.5**	**23**
Nuclear	**332.0**	**398.0**	**304.0**	**348.0**	**352.7**	**9**
Conservation	**284.8[a]**	**290.9**	**226.3**	**191.2**	**165.7**	**25**
Solar, other renewables	**241.7**	**202.1**	**198.3**	**140.5**	**147.9**	**22[b]**
DEFENSE R&D	**1926.2**	**1752.2**	**1729.8**	**1704.4**	**1608.9**	**11**
Weapons R&D	1231.0	1074.0	1077.8	1022.2	978.9	14
Naval reactor development	695.2	678.2	652.0	642.2	630.0	7
TOTAL	**$6162.3**	**$5783.4**	**$5447.1**	**$4757.7**	**$4536.3**	**13%**

Note: Fiscal years. a C&EN estimate based on Congressional action as of Aug. 2, 1991. b Based on estimated appropriation.

NIH BUDGET: Cancer, aging, genome research slated for largest increases

$ Millions	1992 Congressional appropriation[a]	1992 Administration request	1991	1990	1989	Annual change 1991-92[b]
National Institutes	**$8065.9**	**$7982.0**	**$7436.9**	**$6893.8**	**$6561.9**	**8%**
Cancer	1920.3	1810.2	1713.8	1634.3	1570.9	12
Heart, Lung & Blood	1196.5	1209.9	1126.9	1072.3	1045.7	6
Allergy & Infectious Diseases	966.4	976.7	907.3	833.0	742.3	6
General Medical Sciences	817.7	833.2	760.0	712.0	682.2	8
Diabetes & Digestive & Kidney Diseases	660.3	658.6	615.3	581.5	559.6	7
Neurological Disorders & Stroke	583.4	583.4	541.7	490.4	472.3	8
Child Health & Human Development	524.2	520.6	479.0	442.9	425.5	9
Aging	362.6	348.6	323.7	239.5	222.8	12
Eye	269.7	272.3	253.2	236.5	231.3	6
Environmental Health Sciences	252.9	254.5	241.0	229.2	223.7	5
Arthritis & Musculoskeletal & Skin Diseases	204.0	204.8	193.2	168.9	160.0	6
Dental Research	159.7	160.9	148.9	135.7	130.8	7
Deafness & Other Communication Disorders	148.0	148.3	134.9	117.6	94.8	10
National Center for Research Resources	**313.2**	**321.0**	**335.3**	**337.1**	**358.3**	**−7**
National Center for Human Genome Research	**101.2**	**110.5**	**87.4**	**59.5**	**28.0[c]**	**16**
Other	**411.6**	**361.4**	**415.1**	**285.9**	**224.6**	**−1**
TOTAL	**$8891.9**	**$8774.9**	**$8276.7**	**$7576.3**	**$7144.8**	**7%**

Note: Fiscal years. a C&EN estimate based on Congressional action as of Aug. 2, 1991. b Based on estimated appropriation. c Funded under National Institute for General Medical Sciences.

AGRICULTURE R&D: Budget will be up, contrary to funding request

$ Millions	1992 Congressional appropriation[a]	1992 Administration request	1991	1990	1989	% change 1991–92[b]
Agricultural Research Service	$ 701.9	$ 709.2	$ 665.1	$ 596.8	$ 591.7	6%
Cooperative State Research Service	478.0	409.2	451.4	382.8	315.1	6
Forest Service	180.2	163.2	167.6	147.1	137.9	8
National Agricultural Library	17.2	17.5	16.8	14.7	14.3	2
TOTAL	**$1377.3**	**$1299.1**	**$1300.9**	**$1150.4**	**$1064.4**	**6%**

Note: Fiscal years. a C&EN estimate based on Congressional action as of Aug. 2, 1991. b Based on estimated appropriation.

NSF BUDGET: Big increase for education, academic instrumentation funding debuts

$ Millions	1992 Congressional appropriation[a]	1992 Administration request	1991	1990	1989	% change 1991–92[b]
Research and related activities	$1943.2	$1963.5	$1694.2	$1702.4	$1620 5	15%
Education and human resource activities	450.0	390.0	322.4	204.3	171.0	40%
Salaries and expenses	113.0	122.0	101.0	96.4	89.8	12
Antarctic research	98.0	118.0	100.0	71.9	131.0	−2
Academic research facilities	20.0	0	20.5	19.7	0	−2
Academic research instrumentation[c]	50.0	50.0	0	0	0	—
TOTAL	**$2644.2**	**$2643.5**	**$2238.1**	**$2094.7**	**$2012.3**	**18%**

Note: Fiscal years. a C&EN estimate based on Congressional action as of Aug. 2, 1991. b Based on estimated appropriation. c New program proposed by Administration for fiscal 1992.

NASA R&D BUDGET: Space station funding eating into other programs

$ Millions	1992 Congressional appropriation[a]	1992 Administration request	1991	1990	1989	% change 1991–92[b]
Space station and applications	$2648.9	$2909.2	$2518.1	$2007.0	$1855.9	5%
Space station	2022.5	2022.5	1894.5	1714.9	877.3	7
Space transportation capability development	650.0	865.9	658.9	637.3	707.0	−1
Aeronautical research & technology	535.4	582.2	511.5	449.3	395.7	5
Space research & technology	354.3	415.3	305.2	285.2	297.2	16
Commercial programs	99.8	146.8	89.9	58.3	53.1	11
Academic programs	65.9	64.1	61.7	28.2	—	7
Transatmospheric vehicle	48.2	73.2	92.4	59.1	71.2	−48
Safety, reliability & quality assurance	33.6	33.6	35.3	21.9	21.2	−5
Tracking & data systems	21.9	21.9	19.5	19.8	19.3	12
TOTAL	**$6480.5**	**$7134.7**	**$6094.6**	**$5291.9**	**$4297.9**	**5%**

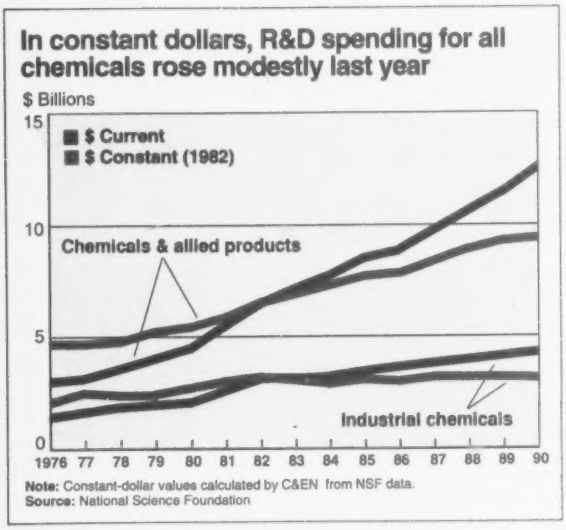
Note: Fiscal years. a C&EN estimate based on Congressional action as of August 2, 1991. b Based on estimated appropriation.

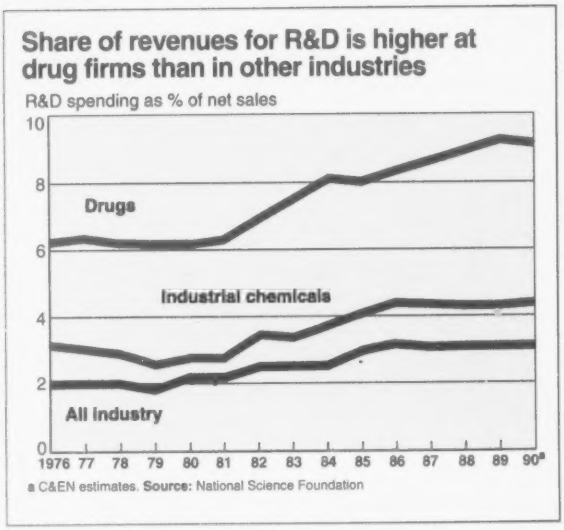
EPA R&D BUDGET: Big boosts for air and pesticides research, only Superfund research declines

$ Millions	1992 Congressional appropriation[a]	1992 Administration request	1991	1990	1989	% change 1991–92[b]
Multimedia	$153.6	$150.7	$124.2	$ 84.0	$ 44.3	24%
Air	119.2	112.4	86.6	77.9	67.7	38
Superfund	68.6	68.6	73.6	78.7	73.4	−7
Hazardous waste	46.7	43.6	39.2	43.9	43.5	19
Water quality	31.1	28.9	27.7	26.9	24.1	7
Toxic substances	26.3	26.3	25.5	27.2	27.9	3
Drinking water	23.7	22.2	20.7	20.9	21.3	14
Pesticides	19.3	15.0	12.6	12.7	13.3	53
Energy/acid rain	15.8	13.7	13.6	33.3	54.5	16
Management & support	5.3	5.3	5.2	14.7	12.6	2
Radiation	5.1	4.0	4.0	3.6	3.5	27
Leaking underground storage tanks	0.8	0.8	0.8	0.7	0.8	0
TOTAL	**$515.5**	**$491.5**	**$433.7**	**$424.5**	**$386.9**	**19%**

Note: Fiscal years. a C&EN estimates based on Congressional action as of Aug. 2, 1991. b Based on estimated appropriation.

Chemicals R&D Outpaces Other Industries


In constant dollars, R&D spending for all chemicals rose modestly last year
$ Billions
15
10
5
0
$ Current
$ Constant (1982)
Chemicals & allied products
Industrial chemicals
1976 77 78 79 80 81 82 83 84 85 86 87 88 89 90
Note: Constant-dollar values calculated by C&EN from NSF data.
Source: National Science Foundation


Share of revenues for R&D is higher at drug firms than in other industries
R&D spending as % of net sales
10
8
6
4
2
0
Drugs
Industrial chemicals
All industry
1976 77 78 79 80 81 82 83 84 85 86 87 88 89 90a
a C&EN estimates. Source: National Science Foundation

TOTAL FUNDS FOR INDUSTRIAL R&D: Overall support increased only 3% in 1990

$ Millions	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	Annual change 1989–90	Annual change 1980–90
Chemicals and allied products	$ 12,700[a]	$ 11,537	$10,774	$ 9,878	$ 8,843	$ 8,540	$ 7,927	$ 7,185	$ 6,604	$ 5,625	$ 4,636	10%	11%
Industrial chemicals	4,300[a]	4,056	3,959	3,901	3,552	3,498	3,240	3,214	3,206	2,802	2,197	6	7
Drugs	6,100[a]	5,400[a]	4,737	4,108[a]	3,658	3,490[a]	3,316[a]	2,901[a]	2,481[a]	2,073[a]	1,777	13	14
Other chemicals	2,300[a]	2,081[a]	2,078	1,869[a]	1,633	1,552[a]	1,371[a]	1,070[a]	917[a]	750[a]	662	11	13
Other industries	91,500[a]	90,062	87,115	82,277	78,980	75,699	66,873	$58,083	52,046	46,185	39,859	2	9
TOTAL	$104,200	$101,599	$97,889	$92,155	$87,823	$84,239	$74,800	$65,268	$58,650	$51,810	$44,505	3%	9%

a C&EN estimates. **Source:** National Science Foundation

COMPANY FUNDS FOR INDUSTRIAL R&D: Outlays for drug R&D grew fastest in 1989

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
Chemicals and allied products	$11,449	$10,580	$ 9,685	$ 8,664	$ 8,310	$ 7,736	$ 6,792	$ 6,197	$ 5,205	$ 4,264	$ 3,692	8%	12%
Industrial chemicals	3,972	3,767	3,714	3,374	3,261	3,057	2,828	2,810	2,393	1,856	1,617	5	9
Drugs	5,206	4,735	4,139	3,657	3,481	3,310	2,896	2,473	2,064	1,756	1,516[a]	10	13
Other chemicals	2,271	2,078	1,832	1,633	1,548	1,369	1,068	914	747	653	559[a]	9	15
Other industries	58,804	55,883	53,121	51,268	48,733	43,668	37,796	33,908	30,223	26,212	22,016	5	10
TOTAL	$70,253	$66,463	$62,806	$59,932	$57,043	$51,404	$44,588	$40,105	$35,428	$30,476	$25,708	6%	11%

a C&EN estimates. **Source:** National Science Foundation

FEDERAL FUNDS FOR INDUSTRIAL R&D: Funds for chemical industry cut in half

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
Chemicals and allied products	$ 88	$ 195	$ 192	$ 179	$ 230	$ 191[a]	$ 393	$ 407	$ 421	$ 372	$ 346	−55%	−13%[a]
Industrial chemicals	84	192	187	178	217	183[a]	386	396	409	341	345	−56	−13[a]
Drugs and other chemicals	4	3	5	1	13	8	7	11	12	31	1	33	15
Other industries	31,278	32,764	31,119	27,712	26,966	23,205	20,287	18,138	15,961	13,657	12,172	−5	10
TOTAL	$31,366	$32,959	$31,311	$27,891	$27,196	$23,396	$20,680	$18,545	$16,382	$14,029	$12,518	−5%	10%

a The decline in 1984 from 1983 results from the administration of federally funded Oak Ridge National Laboratory being changed from a chemical company to a company in the aircraft and missile industry. **Source:** National Science Foundation

COST PER INDUSTRIAL R&D SCIENTIST OR ENGINEER: 5% increase for chemicals in 1989

$ Thousands	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979
Chemicals and allied products	$147.9	$140.4	$127.6	$117.1	$116.3	$112.5	$104.8	$102.5	$ 96.6	$ 87.4	$79.6
Industrial chemicals	176.0	173.6	165.5	150.2	144.5	132.0	123.1	122.1	118.0	103.4	92.8
Drugs	a	141.7	a	113.6	a	a	103.1	a	a	79.2	71.4
Other chemicals	a	101.3	a	83.1	a	a	a	a	a	66.5	66.5
All industry	$140.0	$137.0	$131.2	$128.4	$130.2	$124.0	$116.0	$111.6	$103.9	$ 94.9	$87.4

a Not separately available but included in chemicals and allied products. **Source:** Calculated by C&EN from National Science Foundation data

R&D BY U.S. COMPANIES ABROAD: Funds spent by chemical firms declined sharply in 1989

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
Chemicals and allied products	$1287	$1501	$1243	$1071	$ 843	$ 786	$ 729	$ 682	$ 715	$ 603	$ 500	−14%	10%
Industrial and other chemicals	473	781	625	579	444	385	368	319	287	246	199	−39	9
Drugs	814	720	618	492	399	401	361	363	428	357	301	13	10
Other industries	5232	4794	3983	3553	2807	2847	2540	2412	2678	2562	2254	9	9
TOTAL	$6519	$6295	$5226	$4624	$3650	$3633	$3269	$3094	$3393	$3165	$2754	4%	9%

Source: National Science Foundation

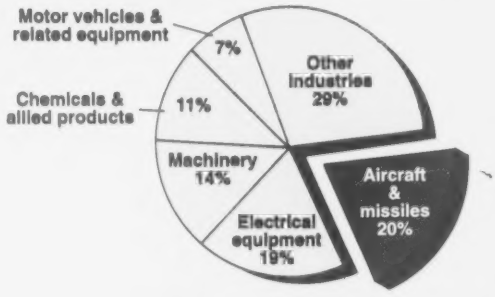
CHEMICAL R&D SPENDING: Company outlays rose 10% in 1990

$ Millions	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1990 R&D spending as % of sales
Du Pont	$1428	$1387	$1319	$1223	$1156	$1144	$1097	$ 966	$ 879	$ 718	$ 591	3.6%
Dow Chemical	1136	873	772	670	605	547	507	492	460	404	314	5.7
Monsanto	612	598	648	615	596	470	370	290	264	233	208	7.7
American Cyanamid	460	406	365	314	278	251	232	208	185	166	148	10.1
Union Carbide[a]	191	181	159	159	148	275	265	245	240	207	166	2.5
Rohm & Haas	178	175	156	142	133	124	109	100	92	77	67	6.3
W. R. Grace	148	125	119	107	94	92	81	73	64	57	45	2.2
Hercules	92	79	74	74	71	76	72	74	74	65	57	2.9
Lubrizol	74	70	65	62	51	44	33	37	36	33	28	5.2
Air Products	72	71	72	57	61	51	44	40	37	32	30	2.5
Olin	66	66	58	62	56	53	52	49	45	38	31	2.5
Ethyl	65[b]	61[b]	59[b]	50	47	47	40	39	39	37	34	2.6
International Flavors	57	52	50	45	39	34	32	32	31	30	29	6.0
Nalco Chemical	45	41	37	35	33	32	32	30	33	30	28	3.7
TOTAL	$4624	$4185	$3953	$3615	$3388	$3240	$2966	$2675	$2479	$2127	$1776	4.5%
ANNUAL CHANGE	10%	6%	9%	7%	4%	9%	11%	8%	17%	20%	16%	

Note: Prior years not restated to reflect company revisions. a Union Carbide divested a substantial part of its business in 1986; on a pro forma basis, R&D spending was $181 million in 1985 and $178 million in 1984. b Adjusted to reflect spin-off of Tredegar Industries. **Source:** Company data

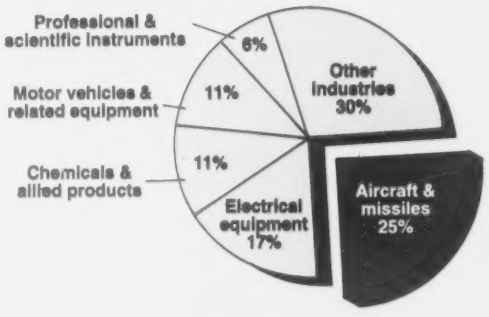
3 R&D Industry

Aircraft and missile firms employ one fifth of R&D scientists and engineers in industry . . .



1989 total industrial R&D scientists and engineers[a] = 726,000

. . . and spend one quarter of total industrial R&D funds in the U.S.



1989 total industrial R&D expenditures = $102 million

a Average full-time equivalent for 1989. **Source:** National Science Foundation

R&D SCIENTISTS AND ENGINEERS IN INDUSTRY: Drug firms show decline

Thousands	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	Annual change 1989–90	Annual change 1980–90
Chemicals and allied products	**78.4**	**77.6**	**75.8**	**75.2**	**75.8**	**71.1**	**69.8**	**67.3**	**61.6**	**54.7**	**51.4**	1%	4%
Industrial chemicals	23.0[a]	23.1[a]	22.5[a]	22.4[a]	24.9	23.5	25.6	26.6	25.9	21.6	20.9	0	2
Drugs	33.0	34.0	33.0	32.6	31.8	30.8	30.8[a]	28.2	25.6	23.3	21.6	−3	4
Other chemicals	22.4	20.5	20.3	20.2	19.1	16.7	13.4	12.1	10.1	9.8	8.9	9	10
Other industries	**653.3**	**642.6**	**632.8**	**620.6**	**595.2**	**551.4**	**514.3**	**473.6**	**448.2**	**433.1**	**399.2**	2	5
TOTAL	**731.7**	**720.2**	**708.6**	**695.8**	**671.0**	**622.5**	**584.1**	**540.9**	**509.8**	**487.8**	**450.6**	2%	5%

Note: Data as of January of each year for full-time equivalent personnel. a C&EN estimates. **Source:** National Science Foundation

CHEMISTS IN INDUSTRY: 15% work outside the manufacturing sector

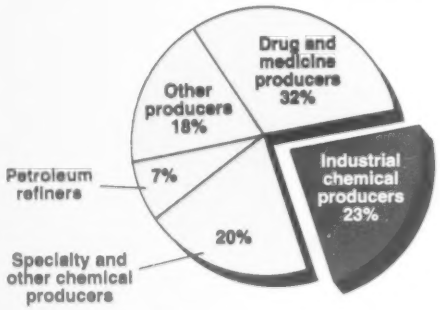
Industry	% of industrial chemists				Mean salary ($ thousands)[a]		
	All chemists	B.S.	M.S.	Ph.D.	B.S.	M.S.	Ph.D.
Manufacturing							
Pharmaceuticals[b]	18%	15%	21%	19%	$46.2	$56.4	$75.3
Specialty chemicals	14	13	11	15	48.7	57.0	67.6
Basic chemicals	6	3	4	8	51.5	68.4	71.7
Plastics	5	3	5	6	51.8	61.6	68.4
Coatings	4	5	3	3	49.7	59.2	62.2
Petroleum and natural gas	4	4	3	5	53.5	65.1	76.2
Medical devices	4	3	3	4	47.2	56.2	71.2
Agricultural chemicals	3	2	2	4	46.3	58.6	67.1
Electronics	3	3	3	3	46.4	58.5	76.2
Food	3	3	4	2	46.4	58.0	72.9
Aerospace	3	3	3	2	51.4	57.5	65.7
Instruments	2	3	3	2	53.0	58.0	66.1
Rubber	2	3	2	1	47.8	51.5	68.5
Biochemical products	1	1	1	2	46.5	61.3	63.2
Metals and minerals	1	2	2	1	38.7	52.0	52.1
Soaps and detergents	1	1	1	2	47.3	49.3	69.8
Paper	1	1	1	1	42.6	55.5	64.5
Other	11	11	11	10	45.8	58.9	68.3
Nonmanufacturing							
Analytical service labs	6	11	6	2	41.1	44.4	64.7
Contract research firms	3	2	3	4	40.9	54.4	58.7
Other	6	8	8	4	51.4	55.7	68.9

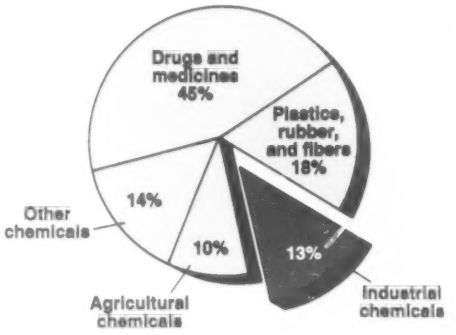
a As of March 1, 1991; to facilitate comparison, mean salaries are adjusted for differences in average length of experience. b Includes personal care products. **Source:** ACS survey

Industrial chemical producers perform almost one quarter of chemical R&D . . .

. . . but industrial chemicals research takes only 13% of such R&D funds

1989 chemical R&D spending[a] = $5.9 billion





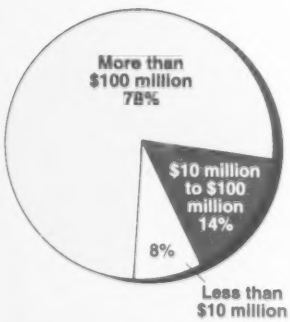
a Excludes basic research. **Source:** National Science Foundation

R&D SCIENTISTS AND ENGINEERS PER 1000 EMPLOYEES: Drug firms lead with 101

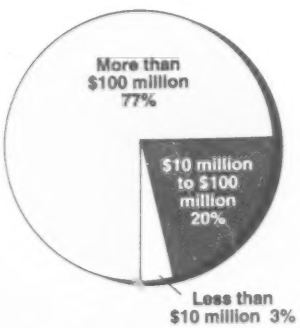
	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979
Chemicals and allied products	72	70	68	70	57	57	54	51	44	42	42
Industrial chemicals	55	55	52	56	39	41	45	44	37	36	36
Drugs	101	99	98	98	81	89	82	74	56	60	62
Other chemicals	65	61	61	63	62	51	39	37	33	30	27
All industry	49	47	45	45	43	40	34	33	29	27	27

Source: National Science Foundation

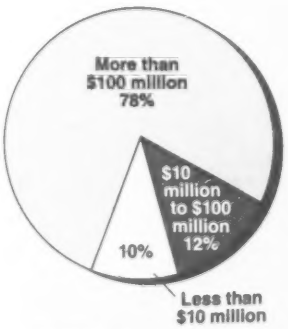
Chemical firms with research budgets under $10 million do their fair share of R&D



1989 chemicals and allied products R&D funds = $11.5 billion



1989 industrial chemicals R&D funds = $4.1 billion

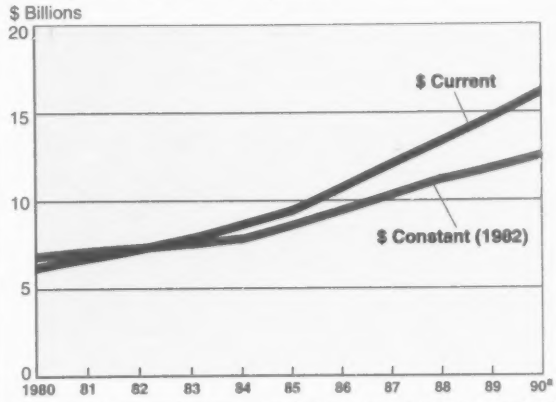


1989 industry R&D funds=$102 billion

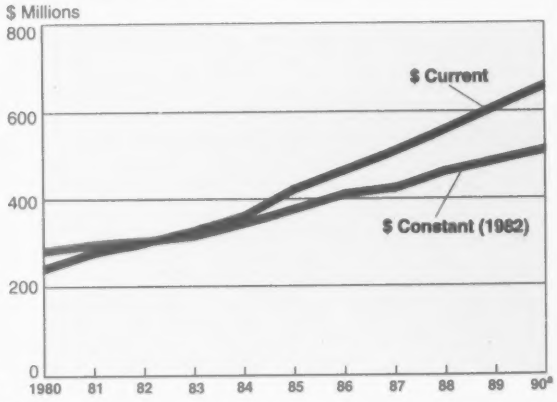
Note: Ranges indicate size of companies' 1989 R&D program. **Source:** National Science Foundation

Universities' R&D Outlays Near $15 Billion

In real terms, R&D funding at universities has grown 80% in 10 years . . .



. . . and is up nearly 80% for chemical research as well



Note: Data for institutional fiscal years. a C&EN estimates. **Source:** National Science Foundation

CHARACTER OF UNIVERSITY R&D SPENDING: In 1989, 35% of total was for applied R&D

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
Basic research	$ 9,685	$ 8,827	$ 8,398	$ 7,495	$6559	$5735	$5304	$4882	$4596	$4041	$3628	10%	10%
Applied research and development	5,303	4,638	3,755	3,431	3128	2882	2573	2441	2250	2035	1752	14	12
TOTAL	$14,987	$13,465	$12,153	$10,926	$9686	$8617	$7877	$7323	$6846	$6077	$5380	11%	11%
ANNUAL CHANGE	11%	11%	11%	13%	12%	9%	8%	7%	13%	13%	16%		

Note: Data for institutional fiscal years. **Source:** National Science Foundation

SOURCE OF UNIVERSITY R&D FUNDS: Institutional contribution up 14% in 1989

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
Federal government	$ 8,972	$ 8,181	$ 7,333	$ 6,702	$6056	$5423	$4983	$4763	$4565	$4104	$3604	10%	10%
Institutional funds	2,710	2,367	2,176	1,873	1622	1413	1303	1115	1008	837	738	14	14
State and local governments	1,239	1,107	1,024	916	754	690	626	616	546	496	476	12	10
Industry	984	870	789	699	559	475	388	337	291	236	194	13	18
Other sources	1,083	941	831	735	695	615	577	492	436	403	368	15	11
TOTAL	$14,987	$13,465	$12,153	$10,926	$9686	$8617	$7877	$7323	$6846	$6077	$5380	11%	11%

Note: Data for institutional fiscal years. **Source:** National Science Foundation

FIELDS OF UNIVERSITY R&D SPENDING: Boost for chemical engineering in 1989

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
All sciences	**$12,600**	**$11,374**	**$10,266**	**$ 9,287**	**$8271**	**$7388**	**$6746**	**$6281**	**$5861**	**$5196**	**$4593**	**11%**	**11%**
Life	8,080	7,258	6,533	5,893	5282	4713	4304	4016	3689	3218	2833	11	11
Physical	1,643	1,547	1,391	1,286	1148	1000	900	823	765	678	602	6	11
Physics	773	732	667	630	551	474	417	367	357	322	292	6	10
Chemistry	610	568	513	469	421	371	335	308	285	245	206	7	11
Environmental	983	885	831	773	703	644	616	557	550	509	453	11	8
Psychology and social	874	767	690	633	541	504	480	484	494	453	396	14	8
Computer	468	411	373	323	283	225	176	149	132	114	98	14	17
Mathematical	214	199	177	152	128	123	106	96	87	79	79	8	10
Others	337	307	272	228	186	179	165	156	145	146	134	10	10
Engineering	**2,388**	**2,091**	**1,887**	**1,638**	**1415**	**1229**	**1130**	**1041**	**968**	**866**	**768**	**14**	**12**
Chemical	185	154	141	126	110	96	91	84	76	68	na	20	—
TOTAL	**$14,987**	**$13,465**	**$12,153**	**$10,926**	**$9686**	**$8617**	**$7877**	**$7323**	**$6829**	**$6062**	**$5361**	**11%**	**11%**
ANNUAL CHANGE	**11%**	**11%**	**11%**	**13%**	**12%**	**9%**	**8%**	**7%**	**13%**	**13%**	**16%**		

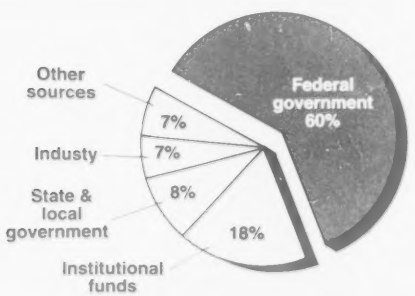
Note: Data for institutional fiscal years. Data since 1981 were revised in 1989. **na** = not available. **Source:** National Science Foundation

FEDERALLY FINANCED R&D SPENDING AT UNIVERSITIES: Growth slows for physical sciences

$ Millions	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
All sciences	**$7593**	**$6956**	**$6224**	**$5726**	**$5191**	**$4637**	**$4238**	**$4059**	**$3898**	**$3500**	**$3069**	**9%**	**9%**
Life	4773	4318	3830	3488	3184	2827	2586	2502	2365	2094	1819	11	10
Physical	1195	1153	1048	982	890	782	699	650	619	555	491	4	9
Physics	598	576	531	510	453	390	343	307	309	280	253	4	9
Chemistry	424	405	368	338	313	279	247	230	217	190	157	5	10
Environmental	645	583	541	515	473	445	426	391	391	372	329	11	7
Psychology and social	367	329	293	287	260	241	236	250	280	263	227	12	5
Computer	318	289	257	232	196	163	128	107	93	77	69	10	17
Mathematical	156	149	131	114	97	92	76	72	68	61	60	5	10
Others	139	133	125	107	92	87	87	88	82	78	73	5	7
Engineering	**1380**	**1225**	**1109**	**976**	**865**	**797**	**744**	**703**	**662**	**596**	**526**	**13**	**10**
Chemical	93	78	70	68	59	55	53	50	48	46	na	19	—
TOTAL	**$8972**	**$8181**	**$7333**	**$6702**	**$6056**	**$5423**	**$4983**	**$4763**	**$4561**	**$4096**	**$3595**	**10%**	**10%**
ANNUAL CHANGE	**10%**	**12%**	**9%**	**11%**	**12%**	**9%**	**5%**	**4%**	**11%**	**14%**	**18%**		

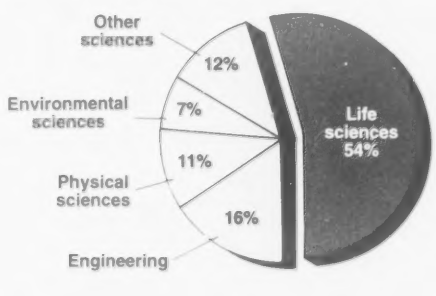
Note: Data for institutional fiscal years. Data since 1981 were revised in 1989. **na** = not available. **Source:** National Science Foundation

Federal government funds 60% of all academic R&D



Fiscal 1989 academic R&D expenditures = $15 billion

Life sciences account for more than half of academic R&D



Fiscal 1989 academic R&D expenditures = $15 billion

Source: National Science Foundation

TOP 10 UNIVERSITY R&D CENTERS: Three labs get 63% of total federal support

$ Millions, fiscal 1989	Physical sciences	Engineering	Math & computer sciences	Environmental sciences	Life sciences	Psychology & social sciences	Other sciences	Total
1 Jet Propulsion Lab	$ 118.0	$ 446.9	$419.2	$ 94.7	$ 0	$ 0	$0	$1078.8
2 Lawrence Livermore National Lab	308.7	483.8	151.0	31.8	29.3	0	0	1004.6
3 Los Alamos National Lab	447.5	311.3	78.7	5.8	33.2	22.8	3.1	902.4
4 Lincoln Lab	69.7	256.2	37.8	0	0	0.4	0	364.1
5 Argonne National Lab	104.2	140.2	5.1	81.9	12.0	0	0	343.3
6 Brookhaven National Lab	186.2	38.7	0.6	7.8	21.2	0.4	0.2	255.2
7 Lawrence Berkeley Lab	146.5	0.2	1.9	10.8	28.7	0	5.1	193.2
8 Fermi National Accelerator Lab	185.1	0	0	0	4.5	0	0	185.1
9 Plasma Physics Lab	112.6	0	0	0	0	0	0	112.6
10 Stanford Linear Accelerator Center	108.7	0	0	0	0	0	0	108.7
All others	81.6	4.1	22.6	65.7	6.2	0.6	0	180.8
TOTAL, ALL FEDERALLY FUNDED R&D CENTERS	$1868.7	$1681.4	$716.8	$298.5	$130.6	$24.2	$8.4	$4728.6

Note: Data for university-administered, federally funded R&D centers. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal 1989 comparisons with data reported in earlier years may be inappropriate in some areas. **Source:** National Science Foundation

CAPITAL SPENDING AT UNIVERSITIES: Environmental sciences make big gain in 1989

$ Millions	1989 Total spending	1989 % federal funds	1988	1987	1986	1985	1984	Annual change 1988–89	Annual change 1984–89
All sciences	$1719.9	9%	$1589.3	$1357.3	$1179.4	$1039.1	$1027.8	8%	11%
Life sciences	1161.9	7	1050.0	909.0	768.3	691.1	716.6	11	10
Physical sciences	237.7	17	204.9	156.8	143.7	115.7	110.1	16	17
Mathematical and computer sciences	67.5	11	95.4	82.7	90.6	77.2	48.9	−29	7
Psychology and social sciences	91.4	11	92.8	64.9	67.7	73.5	78.3	−2	3
Environmental sciences	72.7	26	58.7	54.1	48.9	54.6	36.2	24	15
Other sciences	88.8	10	87.4	89.9	60.1	27.0	37.6	2	19
Engineering	371.8	12	365.3	379.8	314.1	183.6	146.9	2	20
TOTAL	$2091.7	11%	$1954.6	$1737.1	$1493.5	$1222.7	$1174.6	7%	12%
ANNUAL CHANGE	7%	—	13%	16%	22%	4%	8%		

Note: Data for institutional fiscal years. Includes expenditures for facilities and equipment for research, development, and instruction. **Source:** National Science Foundation

UNIVERSITY SPENDING FOR RESEARCH EQUIPMENT: Slight drop for physical sciences

$ Millions	1989 Total	1989 Federal funds	1988 Total	1988 Federal funds	1982 Total	1982 Federal funds	Annual change 1988–89 Total	Annual change 1988–89 Federal funds	Annual change 1982–89 Total	Annual change 1982–89 Federal funds
All sciences	$792.9	$476.9	$725.4	$459.6	$350.1	$223.6	9%	4%	13%	11%
Life sciences	442.4	239.5	386.4	215.8	201.9	116.5	14	11	12	11
Physical sciences	179.4	131.7	180.9	142.1	79.8	63.8	−1	−7	12	11
Physics	81.8	64.1	84.7	67.4	33.7	29.0	−3	−5	14	12
Chemistry	75.8	53.0	74.6	57.7	33.4	24.8	2	−8	12	11
Environmental sciences	66.4	44.8	55.6	36.6	28.5	18.4	19	22	13	14
Mathematical and computer sciences	52.9	35.9	54.1	42.2	16.3	12.4	−2	-15	16	16
Other sciences	51.8	25.0	48.5	22.9	21.8	12.5	7	9	13	10
Engineering	205.0	117.3	195.7	117.8	71.3	46.9	5	0	16	14
Chemical	18.6	9.5	15.0	8.0	6.6	3.8	24	19	16	14
TOTAL	$997.9	$594.2	$921.1	$577.4	$421.4	$270.4	8%	3%	13%	12%

Note: Data for institutional fiscal years. **Source:** National Science Foundation

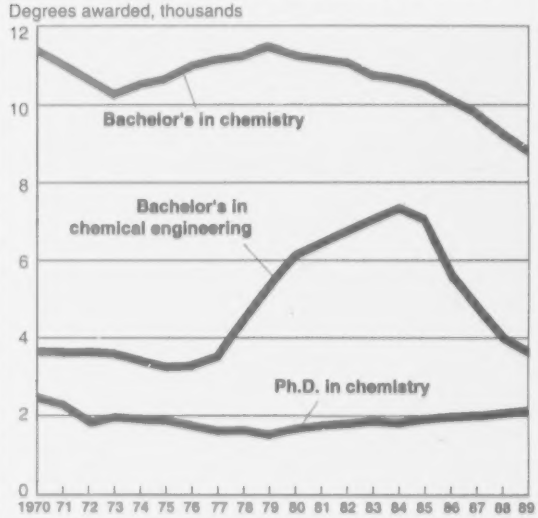
CHEMICAL DEGREES: Annual production of B.S. chemists down 26% from 1979 peak

Academic year	Degrees awarded in chemistry			Degrees awarded in chemical engineering		
	Bachelor's	Master's	Ph.D.	Bachelor's	Master's	Ph.D.
1970	11,617	2146	2208	3720	1045	438
1971	11,183	2284	2160	3615	1100	406
1972	10,721	2259	1971	3663	1154	394
1973	10,226	2230	1882	3636	1051	397
1974	10,525	2138	1828	3454	1045	400
1975	10,649	2006	1824	3142	990	346
1976	11,107	1796	1623	3203	1031	308
1977	11,322	1775	1571	3581	1086	291
1978	11,474	1892	1525	4615	1237	259
1979	11,643	1765	1518	5655	1149	304
1980	11,446	1733	1551	6383	1271	284
1981	11,347	1654	1622	6527	1267	300
1982	11,062	1751	1722	6740	1285	311
1983	10,746	1604	1746	7145	1304	319
1984	10,704	1667	1744	7475	1514	330
1985	10,482	1719	1789	7146	1544	418
1986	10,116	1754	1908	5877	1361	446
1987	9,661	1738	1976	4983	1184	497
1988	9,052	1708	1995	3917	1088	579
1989	8,654	1785	2034	3684	1097	599

Source: National Center for Education Statistics

Another slight gain for chemistry Ph.D.s

Degrees awarded, thousands



Note: Academic years. **Source:** National Center for Education Statistics

TOP 10 UNIVERSITIES IN R&D SPENDING: Ten schools spend 20% of total

$ Millions, fiscal 1989	Physical sciences	Chemistry*	Engineering	Environmental sciences	Life sciences	Math & computer sciences	Other sciences	Total
1 Johns Hopkins U	$ 85.8	$ 5.2	$ 209.7	$ 44.0	$ 180.1	$104.8	$ 23.9	$ 648.4
2 Massachusetts Institute of Technology	89.9	14.0	116.4	11.6	34.3	13.6	21.4	287.2
3 Cornell U	43.2	10.2	38.6	5.5	163.6	21.5	14.2	286.7
4 Stanford U	50.7	10.1	78.3	5.2	129.4	15.7	6.8	286.0
5 U of Wisconsin, Madison	27.2	8.3	34.7	20.9	165.1	8.5	29.5	286.0
6 U of Michigan	15.7	3.8	46.7	16.1	143.2	8.1	50.8	280.9
7 U of Minnesota	14.4	5.9	27.7	7.2	187.3	6.7	15.3	258.6
8 Texas A&M U	19.7	9.8	52.5	52.2	103.0	4.0	19.2	250.7
9 U of California, Los Angeles	21.8	9.9	23.0	11.3	144.9	6.6	20.3	227.8
10 U of Washington	13.4	5.2	16.7	19.2	136.2	8.3	28.0	221.7
TOTAL, FIRST 10 INSTITUTIONS	$ 382.0	$ 83.3	$ 644.6	$193.2	$1387.2	$197.8	$ 229.3	$ 3,034.0
TOTAL, ALL INSTITUTIONS	$1643.4	$610.4	$2387.6	$982.9	$8079.9	$682.0	$1211.5	$14,987.3

Note: Data for institutional fiscal years. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal 1989 comparisons with data reported in earlier years may be inappropriate in some areas. a Included in physical sciences. **Source:** National Science Foundation

SCHOOLS SPENDING MOST ON CHEMICAL R&D: 18% of total goes to 10 institutions

Rank 1989	Rank 1988		1989 Total spending ($ thousands)	1989 % federal funds	1988 ($ thousands)	1987 ($ thousands)	1986 ($ thousands)	1985 ($ thousands)	1984 ($ thousands)	Annual change 1988–89	Annual change 1984–89
1	2	Massachusetts Inst. of Technology	$ 15,031	89%	$ 13,287	$ 11,471	$ 13,593	$ 13,221	$ 11,741	13%	5%
2	1	U of California, Berkeley	12,663	91	14,285	12,490	9,114	10,804	7,850	−11	10
3	7	Harvard U	11,856	89	9,886	8,895	7,202	6,557[a]	6,307[a]	20	13
4	3	U of Texas, Austin	11,484	53	10,943	11,420	8,531	7,908	6,639	5	12
5	5	Cornell U	10,217	73	10,472	8,397	7,376	7,962	6,710	−2	9
6	4	Stanford U	10,098	88	10,547	8,916	8,340	8,354	6,809	−4	8
7	8	U of California, Los Angeles	9,855	92	9,519	10,099	7,954	7,243	7,219	4	6
8	9	Texas A&M U	9,808	45	8,785	7,462	7,230[a]	6,768[a]	5,606[a]	16	12
9	12	U of Maryland, College Park	9,732	39	8,545	9,258	7,904	7,289	6,324	14	9
10	14	U of Chicago	9,333	92	8,046	7,514	7,553[a]	6,921[a]	5,735	16	10
		Total, first 10 institutions	$110,077	76%	$104,315	$ 95,922	$ 84,797	$ 83,027	$ 70,940	6%	9%
11	6	California Inst. of Technology	9,235	81	9,931	10,870	9,176	7,605	6,446	−7	7
12	10	U of Illinois, Urbana	9,208	71	8,647	9,035	8,604	7,079	6,284	6	8
13	13	Princeton U	8,873	64	8,087	6,477	5,702	3,963	3,670	10	19
14	11	Purdue U	8,769	81	8,615	7,092	6,315	6,018	5,443	2	10
15	17	Pennsylvania State U	8,616	76	7,739	6,072	6,438	6,509	5,124	11	11
16	20	U of Wisconsin, Madison	8,326	66	7,282	6,984	7,892	7,350	6,076	14	7
17	15	Case Western Reserve U	8,233	63	7,996	7,164	2,922[a]	2,802	2,759	3	24
18	16	Indiana U	7,927	77	7,991	6,181	6,110	5,820	5,551	−1	7
19	28	Rutgers U	7,905	83	5,926	3,913	3,507	2,368	2,301	33	28
20	19	U of Pennsylvania	7,760	91	7,292	6,741	6,064	5,025	4,375	6	12
		Total, first 20 institutions	$194,929	76%	$183,821	$166,451	$147,527	$137,566	$118,969	6%	10%
21	26	Northwestern U	7,661	73	6,644	6,095	4,826	5,062	4,557	15	11
22	22	Rockefeller U	7,471	50	6,975	6,823	7,335	4,826[a]	1,178	7	45
23	23	Columbia U, main division	7,120[b]	94	6,931	6,715	5,555	5,188	4,662	3	9
24	18	Ohio State U	6,771	66	7,568	5,755	6,546	5,422	4,104	−11	11
25	21	U of Notre Dame	6,660	90	7,004	5,550	5,402	5,549	4,760	0	7
26	29	U of Colorado	6,587	82	5,637	5,118	5,830	6,360	4,134	17	7
27	25	U of California, San Diego	6,487	89	6,780	5,179	6,535	4,642	4,355	−4	8
28	24	Yale U	5,915	85	6,869	5,538	6,169[a]	5,600[a]	4,134	−14	7
29	33	U of Minnesota	5,863	86	5,232	5,426	5,110	4,167	4,067	12	8
30	30	U of Pittsburgh	5,736	79	5,598	5,105	4,974	4,580	3,965	2	8
		Total, first 30 institutions	$261,200	78%	$249,059	$233,755	$205,809	$188,962	$158,885	5%	10%
31	39	U of Utah	5,653	68	4,600	4,846	5,354	4,840	3,830	23	8
32	40	Wayne State U	5,557	54	4,582	3,278	3,405	2,903	3,071	21	13
33	31	U of Oregon	5,501	81	5,550	4,462	5,087	4,640	4,255	−1	5
34	46	Florida State U	5,382	37	4,308	3,841	4,047	3,276	3,137	25	11
35	27	Georgia Inst. of Technology	5,380	56	5,989	4,889	5,260	3,684	3,846	−10	7
36	62	Arizona State U	5,260	60	4,306	3,586	4,124	2,703	2,875	22	13
37	45	U of Washington	5,192	72	4,338	3,655	2,971	2,964	2,340	20	17
38	43	U of North Carolina, Chapel Hill	5,171	88	4,476	3,471	3,352	3,386	2,945	16	12
39	38	Virginia Polytechnic Inst. & State U	5,155	43	4,735	4,190	3,786	4,840	3,830	9	6
40	34	Johns Hopkins U	5,152	94	5,211	5,593	5,506	4,652[a]	4,030	−1	5
		Total, first 40 institutions	$314,603	75%	$297,154	$265,566	$248,701	$226,850	$193,044	6%	10%
41	48	U of Virginia	5,096	82	4,153	4,169	3,436	3,046	2,516	23	15
42	35	U of Florida	5,061	56	5,030	5,690	4,750	4,380	4,024	1	5
43	51	U of Tennessee System	4,960	60	3,962	2,611	2,501	na	na	25	—
44	56	U of Kansas	4,952	41	3,845	2,803	1,818	1,875[b]	1,405[b]	29	29
45	61	U of Houston	4,908	43	3,693	4,003	3,225	2,722	2,117	33	18
46	44	U of Rochester	4,762	91	4,437	3,545	3,584	3,196	3,858	7	4
47	36	State U of New York, Stony Brook	4,754	76	5,010	3,669	3,333	3,481	3,084	−5	9
48	57	Louisiana State U	4,698	48	3,834	3,446	3,195	2,664	1,438	23	27
49	50	U of Cincinnati	4,655	59	4,008	3,816	1,684	1,593	1,633	16	23
50	54	State U of New York, Buffalo	4,644	60	3,903	3,370	2,837	2,768	2,407	19	14
		Total, first 50 institutions	$343,093	73%	$319,029	$302,688	$279,064	$252,575	$215,526	7%	11%
		NATIONAL TOTAL	$610,394	69%	$567,622	$513,102	$469,275	$421,506	$369,945	7%	11%

Note: Data for institutional fiscal years. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal-year 1989 comparisons with data reported in earlier years may be inappropriate in some areas. Data for 1986 and later were revised in 1989. a Estimated. b Imputed. na = not available. **Source:** National Science Foundation

SCHOOLS WITH MOST FEDERAL SUPPORT FOR CHEMICAL R&D: **Three get over $10 million each**

Rank 1989	Rank 1988		1989	1988	1987	1986	1985	1984	Annual change 1988–89	Annual change 1984–89
			($ thousands)							
1	2	Massachusetts Inst. of Technology	$ 13,333	$ 11,987	$ 10,656	$ 12,909	$ 12,424	$ 11,055	11%	4%
2	1	U of California, Berkeley	11,450	12,998	11,160	8,258	9,892	7,263	−12	10
3	4	Harvard U	10,594	9,272	8,309	6,748	6,557	6,307	14	11
4	5	U of California, Los Angeles	9,024	8,885	9,414	7,516	6,389	5,047	2	12
5	3	Stanford U	8,878	9,423	7,918	7,524	7,097	6,120	−6	8
6	8	U of Chicago	8,621	7,235	6,499	6,769[a]	6,265[a]	5,116	19	11
7	6	California Inst. of Technology	7,459	8,769	9,922	7,612	7,001	5,810	−15	5
8	7	Cornell U	7,458	8,269	6,753	5,934	6,293	5,775	−10	5
9	9	Purdue U	7,102	7,120	5,978	5,708	5,418	4,452	0	10
10	14	U of Pennsylvania	7,046	6,337	5,653	5,232	4,398	3,921	12	12
		Total, first 10 institutions	$ 90,965	$ 90,295	$ 82,262	$ 74,210	$ 71,734	$ 60,866	1%	8%
11	11	Columbia U, main division	6,676	6,519	6,625	5,030	4,490	4,639	2	8
12	39	Rutgers U	6,572	3,442	2,525	2,123	2,055	2,129	91	25
13	15	U of Illinois, Urbana	6,566	6,193	6,306	5,999	5,371	5,005	6	6
14	17	Pennsylvania State U	6,515	5,957	4,915	5,161	5,860	4,564	9	7
15	13	Indiana U	6,127	6,354	4,923	4,757	4,885	4,694	−4	10
16	12	U of Texas, Austin	6,120	6,443	6,405	4,922	4,741	3,873	−5	10
17	10	U of Notre Dame	5,983	6,557	5,158	4,998	5,097	4,416	−9	6
18	16	U of California, San Diego	5,757	6,161	4,599	5,918	4,053	3,780	−7	9
19	19	Princeton U	5,681	5,812	5,064	4,575	3,104	2,892	−2	14
20	22	Northwestern U	5,577	4,955	4,641	3,753	3,963	3,471	13	10
		Total, first 20 institutions	$152,539	$148,686	$133,423	$121,446	$115,353	$100,329	3%	9%
21	24	U of Wisconsin, Madison	5,505	4,939	4,718	5,348	5,156	4,391	11	5
22	27	U of Colorado	5,418	4,603	4,402	4,911	5,430	3,358	18	10
23	21	Case Western Reserve U	5,161	5,433	5,016	2,062	2,065	1,904	−5	22
24	32	U of Minnesota	5,054	4,156	4,395	4,013	3,295	3,346	22	9
25	18	Yale U	5,011	5,927	4,909	5,566[a]	5,095[a]	3,528	−15	7
26	25	Johns Hopkins U	4,824	4,830	5,116	4,903	4,155	3,783	0	5
27	26	U of Pittsburgh	4,558	4,803	4,028	4,045	3,836	3,343	−5	6
28	31	U of North Carolina, Chapel Hill	4,534	4,193	3,153	2,929	2,885	2,699	8	11
29	20	Ohio State U	4,445	5,437	4,517	4,931	3,846	2,904	−18	9
30	28	U of Oregon	4,435	4,519	3,579	4,345	3,959	3,524	−2	5
		Total, first 30 institutions	$201,484	$197,526	$177,256	$164,499	$155,075	$133,109	2%	9%
31	23	Texas A&M U	4,408	4,945	4,019	3,128	4,195	2,735	−11	10
32	33	U of Rochester	4,327	3,936	3,275	3,336	2,861	3,490	10	4
33	40	U of Virginia	4,165	3,419	3,281	2,748	2,165	2,099	22	15
34	37	U of Southern California	3,986	3,568	2,903	2,857	2,149	2,495	12	10
35	35	U of Utah	3,872	3,614	4,194	4,791	4,426	3,380	7	3
36	34	U of Maryland, College Park	3,844	3,793	4,073	3,557	3,323	2,862	1	6
37	47	U of Washington	3,756	2,904	2,287	1,898	1,738	1,843	29	15
38	45	Rockefeller U	3,713	3,082	3,247	3,377	2,553	833	20	35
39	29	U of California, Irvine	3,685	4,376	3,386	3,394	3,035	2,096	−16	12
40	38	State U of New York, Stony Brook	3,610	3,460	2,930	2,168[a]	2,343	2,069	4	12
		Total, first 40 institutions	$240,850	$234,525	$210,851	$195,753	$183,863	$157,011	3%	9%
41	30	Colorado State U	3,457	4,280	3,273	3,403	2,434	2,426	−19	7
42	58	U of California, Davis	3,386	2,255	1,980	2,175	1,702	1,478	50	18
43	43	U of California, Santa Barbara	3,242	3,196	3,526	3,087	2,709	1,881	1	12
44	51	Arizona State U	3,172	2,813	2,317	2,218	2,306	2,014	13	10
45	60	Georgetown U	3,113	2,148	2,155	2,252	1,075	822	45	31
46	57	Washington U	3,088	2,291	1,759	1,477	1,547	1,629	35	14
47	48	U of Arizona	3,044	2,885	2,499	2,291	1,738	1,843	6	11
48	41	U of Michigan	3,022	3,310	2,615	2,367	2,286	2,356	−9	5
49	36	Georgia Inst. of Technology	3,020	3,574	2,565	2,914	2,051	2,227	−16	6
50	59	Wayne State U	2,989	2,151	1,770	1,690	2,076	2,104	39	7
		Total, first 50 institutions	$272,383	$263,528	$235,310	$219,627	$203,787	$175,791	3%	9%
		NATIONAL TOTAL	$433,731	$405,017	$367,753	$338,027	$312,831	$278,215	5%	9%

Note: Data for institutional fiscal years. A number of institutions have developed or are in the process of developing new computer systems and methodologies that enable them to report more accurately the total cost of science and engineering research. Fiscal-year 1989 comparisons with data reported in earlier years may be inappropriate in some areas. Data for 1986 and later were revised in 1989. a. Estimated. **Source:** National Science Foundation

SCHOOLS SPENDING MOST ON CHEMICAL ENGINEERING R&D: MIT way out in front

Rank 1989	Rank 1988		Chemical engineering: Total spending ($ thousands)	Chemical engineering: Federal funds	Chemical engineering: % federal funds	All engineering: Total spending ($ thousands)	All engineering: Federal funds	All engineering: % federal funds
1	1	Massachusetts Inst. of Technology	$ 13,493	$ 9,359	69%	$ 116,367	$ 80,356	69%
2	2	U of Minnesota	8,403	5,279	63	27,709	10,421	38
3	3	U of Texas, Austin	6,109	2,253	37	50,944	22,894	45
4	14	Columbia U, main division	5,308	3,059	58	15,429	9,386	62
5	6	Johns Hopkins U	4,842	4,352	90	209,748	206,629	99
6	5	U of Maryland, College Park	4,548	1,514	33	41,624	15,655	38
7	17	U of Pennsylvania	4,355	3,452	79	9,981	6,439	65
8	4	Texas A&M U	4,159	706	17	52,541	14,743	28
9	9	U of Wisconsin, Madison	3,839	2,096	55	34,697	21,745	63
10	11	Case Western Reserve U	3,378	2,104	62	18,089	13,173	73
		Total, first 10 institutions	$ 58,434	$34,174	58%	$ 576,769	$ 401,441	70%
11	7	North Carolina State U, Raleigh	3,304	861	26	34,421	11,209	33
12	12	U of Delaware	3,147	895	28	10,874	4,461	41
13	8	Stanford U	2,939	2,564	87	78,311	65,502	84
14	10	Brigham Young U	2,867[a]	2,290[a]	80	5,127[a]	3,231[a]	63
15	19	Lehigh U	2,742	523	19	18,214	6,186	34
16	15	Pennsylvania State U	2,674	991	37	97,276	59,260	61
17	26	U of Houston	2,396	994	41	8,020	3,137	39
18	18	Princeton U	2,367	1,103	47	20,957	10,508	50
19	22	U of California, Los Angeles	2,238	1,597	71	22,975	16,679	73
20	24	Auburn U	2,217	754	34	16,996	7,664	45
		Total, first 20 institutions	$ 85,325	$46,746	55%	$ 889,940	$ 589,278	66%
21	13	U of Michigan	2,207	1,482	67	46,866	27,507	59
22	16	Cornell U	2,206	1,250	57	38,648	22,630	59
23	34	U of Oklahoma	2,189	505	23	8,529	2,247	26
24	20	Georgia Inst. of Technology	2,124	1,192	56	116,109	65,178	56
25	21	California Inst. of Technology	2,047	1,635	80	16,670	13,641	82
26	23	Purdue U	2,042	1,245	61	32,873	18,733	57
27	47	Rutgers U	2,034	722	35	19,463	3,680	19
28	25	U of Washington	2,022	1,097	54	16,738	10,581	63
29	29	New Mexico Inst. of Mining & Tech.	2,017	366	18	16,325	4,378	27
30	52	Louisiana State U	2,015	788	39	13,216	2,979	23
		Total, first 30 institutions	$106,228	$57,028	54%	$1,215,377	$ 760,832	63%
		NATIONAL TOTAL	$185,087	$92,947	50%	$2,387,593	$1,379,664	58%

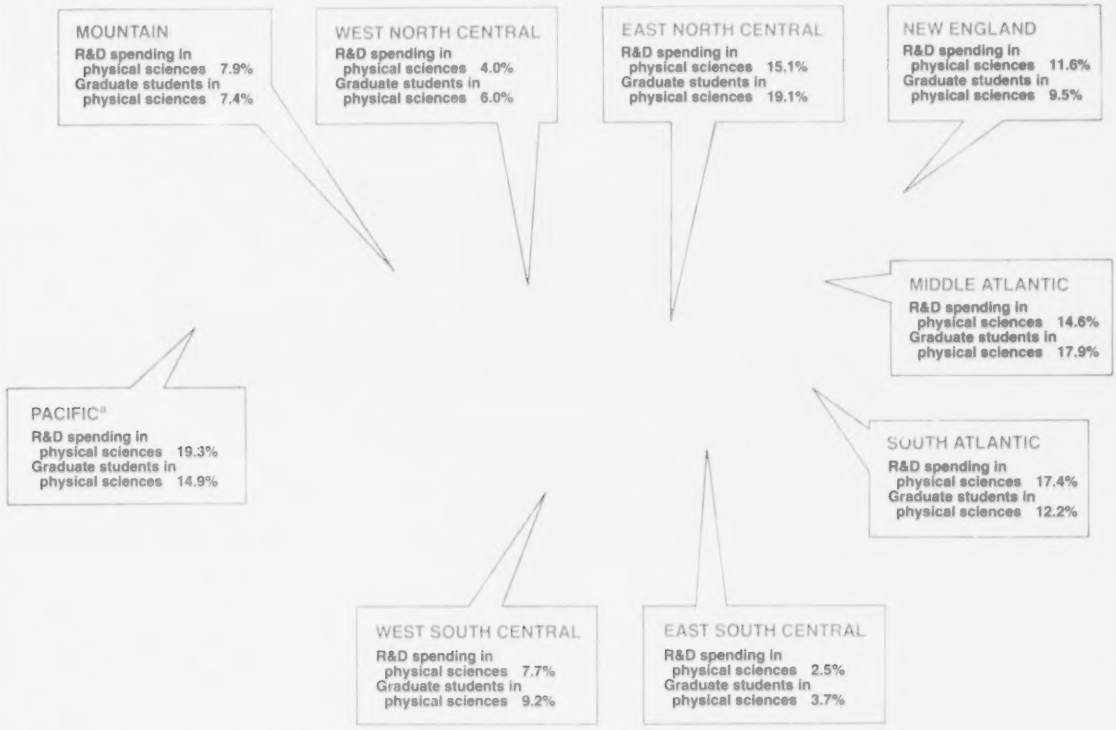
Note: Data for fiscal 1989. a Estimated. **Source:** National Science Foundation

FOREIGN GRADUATE STUDENTS: Most common in engineering, physics, and math

	1989 Thousands	1989 % of total	1988 Thousands	1988 % of total	1987 Thousands	1987 % of total	1986 Thousands	1986 % of total	1985 Thousands	1985 % of total	1984 Thousands	1984 % of total	Annual change 1988–89	Annual change 1984–89
All sciences	**51.1**	**28%**	**49.1**	**28%**	**46.0**	**27%**	**43.5**	**26%**	**39.7**	**24%**	**36.1**	**22%**	**4%**	**7%**
Psychology and social sciences	13.5	20	13.6	21	12.8	20	12.4	20	11.8	19	10.8	18	–1	5
Mathematical and computer sciences	12.1	44	11.6	44	11.0	42	10.4	41	9.5	41	8.3	40	4	8
Biological sciences	9.9	25	8.9	23	7.9	21	7.0	19	6.2	17	5.6	16	11	12
Biochemistry	1.5	30	1.3	28	1.2	26	1.1	23	1.0	22	0.8	20	15	13
Physical sciences	10.9	38	10.2	37	9.8	35	9.3	34	8.3	32	7.4	30	7	8
Chemistry	5.6	35	5.2	33	4.8	31	4.4	28	4.0	26	3.5	24	8	10
Physics	5.1	44	4.9	43	4.8	43	4.7	44	4.1	41	3.8	38	4	6
Agricultural sciences	2.5	29	2.5	30	2.5	30	2.5	28	2.3	26	2.3	25	0	2
Earth, atmospheric, and ocean sciences	2.3	24	2.1	22	1.9	19	1.9	17	1.6	15	1.6	14	9	8
Engineering	**29.1**	**47**	**28.8**	**47**	**27.4**	**45**	**26.4**	**45**	**23.5**	**43**	**22.6**	**42**	**1**	**5**
Chemical	2.6	49	2.4	45	2.3	41	2.2	39	2.2	40	2.1	37	8	4
Metallurgical and materials	1.8	49	1.6	48	1.6	47	1.5	45	1.3	42	1.2	42	12	8
TOTAL	**80.2**	**33%**	**77.9**	**33%**	**73.4**	**32%**	**69.9**	**31%**	**63.2**	**29%**	**58.7**	**27%**	**3%**	**6%**
ANNUAL CHANGE	**3%**		**6%**		**5%**		**11%**		**8%**		**3%**			

Note: Data are for full-time graduate students at Ph.D-granting institutions only. The percent of total is the percent of all full-time graduate students in each area who are foreign. **Source:** National Science Foundation

Physical sciences: East and West Coast schools get 63% of R&D funds, 55% of grad students


MOUNTAIN
R&D spending in physical sciences 7.9%
Graduate students in physical sciences 7.4%
WEST NORTH CENTRAL
R&D spending in physical sciences 4.0%
Graduate students in physical sciences 6.0%
EAST NORTH CENTRAL
R&D spending in physical sciences 15.1%
Graduate students in physical sciences 19.1%
NEW ENGLAND
R&D spending in physical sciences 11.6%
Graduate students in physical sciences 9.5%
MIDDLE ATLANTIC
R&D spending in physical sciences 14.6%
Graduate students in physical sciences 17.9%
PACIFIC[a]
R&D spending in physical sciences 19.3%
Graduate students in physical sciences 14.9%
SOUTH ATLANTIC
R&D spending in physical sciences 17.4%
Graduate students in physical sciences 12.2%
WEST SOUTH CENTRAL
R&D spending in physical sciences 7.7%
Graduate students in physical sciences 9.2%
EAST SOUTH CENTRAL
R&D spending in physical sciences 2.5%
Graduate students in physical sciences 3.7%

Key to map: Using the Middle Atlantic states as an example, 14.6% of all R&D expenditures in the physical sciences and 17.9% of all graduate students in physical sciences are in this area. The figures for funding apply to Ph.D.-granting universities and colleges only. The figures for students apply to all universities and colleges.

Note: Data are based on $1.6 billion of R&D expenditures and 33,584 graduate students in the physical sciences enrolled in colleges and universities during the 1989 fiscal year. **a** Includes Alaska, Hawaii, and outlying areas. **Source:** National Science Foundation

GRADUATE SCIENCE STUDENTS: Growth slow for chemistry as for all fields

Thousands	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
All sciences	241.9	237.4	233.6	230.1	226.1	220.5	220.4	220.7	217.1	227.1	219.8	2%	1%
Psychology and social sciences	97.7	94.7	93.0	90.7	90.3	89.1	92.1	96.5	98.1	109.7	105.8	3	−1
Biological sciences	45.8	44.6	43.6	43.4	42.5	42.0	41.6	41.9	42.1	42.7	42.6	3	1
Biochemistry	5.1	4.9	4.8	4.9	4.7	4.5	4.2	4.1	4.0	4.0	3.9	4	3
Mathematical and computer sciences	43.6	43.7	42.3	40.9	39.1	35.4	33.2	30.4	27.2	25.0	22.7	0	7
Physical sciences	31.7	31.2	31.0	30.5	29.3	28.4	27.7	26.5	25.8	25.4	24.9	2	2
Chemistry	17.7	17.5	17.7	17.6	17.2	16.6	16.5	15.8	15.3	15.1	14.9	1	2
Physics	13.1	12.8	12.3	12.0	11.3	11.0	10.5	10.0	9.9	9.6	9.3	2	3
Earth, atmospheric, and ocean sciences	12.6	12.9	13.4	14.0	14.2	14.3	14.3	13.8	13.1	12.8	12.8	−2	0
Agricultural sciences	10.4	10.3	10.3	10.7	10.7	11.3	11.5	11.6	11.4	11.6	11.3	1	−1
Engineering	97.0	96.7	97.0	95.8	90.2	87.1	85.3	78.2	74.4	70.1	67.2	0	4
Chemical	6.3	6.5	7.0	6.9	7.0	7.2	7.4	6.9	6.3	5.9	5.4	−3	2
Metallurgical and materials	4.4	4.2	4.2	4.0	3.8	3.6	3.3	3.0	3.0	2.8	2.7	5	5
Petroleum	0.7	0.7	0.8	0.7	0.8	0.7	0.7	0.6	0.5	0.5	0.4	0	6
TOTAL	338.9	334.1	330.6	325.9	316.3	307.6	305.7	298.9	292.0	297.3	287.0	1%	2%
ANNUAL CHANGE	1%	1%	1%	3%	3%	1%	2%	2%	−2%	4%	3%		

Note: Data for Ph.D-granting institutions only. Data for 1981 and later were revised in 1990. **Source:** National Science Foundation

U.S. Still Dominates in Worldwide R&D, But Germany, Japan Make Faster Progress

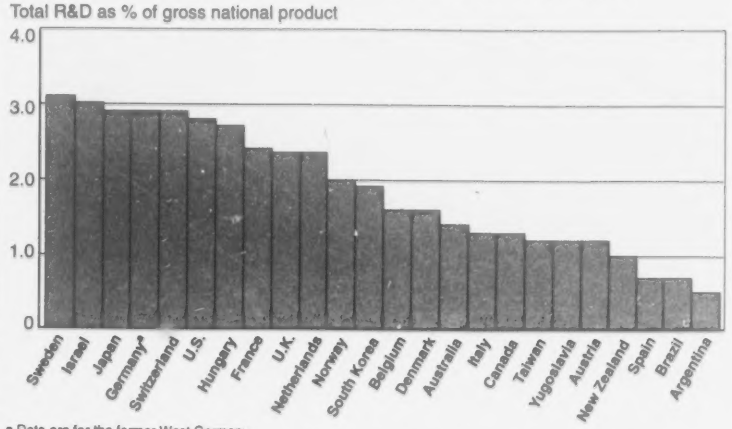
WORLDWIDE R&D SCIENTISTS AND ENGINEERS: Japan's upswing continues

Thousands	1989	1988	1987	1986	1985	1984	1983	1982	1981
U.S.	na	949	923	897	849	798	752	712	683
Japan[a]	458	435	416	393	381	357	347	na	na
Germany[b]	na	na	166	na	144	na	131	na	125
France	na	115	109	105	102	98	93	90	86
U.K.[c]	na	na	127	127	123	na	na	na	na
Italy	na	75	71	68	64	62	63	57	52
Canada	na	61	59	57	53	49	46	45	41
Netherlands	na	na	na	na	24	na	22	na	19
Sweden	na	na	23	na	22	na	19	na	18
Spain[d]	na	na	21	19	16	15	14	14	14
Norway	12	na	11	na	10	9	8	8	7
Denmark	na	11	10	9	9	8	8	7	7

Note: Table represents all scientists and engineers engaged in R&D on a full-time equivalent basis. a Revised to reflect full-time equivalent. b Data are for former West Germany. c Based on underestimated data because persons in the private nonprofit sector are excluded. d R&D personnel in the education sector include only researchers. na = not available.
Source: Organization for Economic Cooperation & Development

Only Sweden spends more than 3% of GNP on R&D

Total R&D as % of gross national product



a Data are for the former West Germany.
Sources: Organization for Economic Cooperation & Development, National Science Foundation

WORLDWIDE R&D EXPENDITURES: Five countries spend more than $10 billion on R&D annually

$ Millions, constant 1982		% of GNP	$ Millions, constant 1982		% of GNP	$ Millions, constant 1982		% of GNP
U.S. (1989)	$111,129	2.7%	**Switzerland** (1989)	$2690	2.9%	**Austria** (1991)	$1281	1.2%
Japan (1989)	45,906	3.0	**India** (1989)	2514	1.0	**Brazil** (1987)	1275	0.7
Germany[a] (1989)	21,911	2.9	**Australia** (1988)	2413	1.4	**Finland** (1989)	1078	1.2
France (1989)	15,039	2.3	**Spain** (1989)	2264	0.7	**Norway** (1989)	1066	2.0
U.K. (1989)	13,196	2.2	**Belgium** (1988)	1729	1.6	**Denmark** (1989)	909	1.6
Italy (1989)	8,183	1.3	**South Korea** (1988)	1613	1.9	**Israel** (1983)	637	3.0
Canada (1990)	5,486	1.3	**Taiwan** (1988)	1555	1.2	**Hungary** (1987)	588	2.7
Netherlands (1988)	3,632	2.2	**Argentina** (1988)	1326	0.5	**New Zealand** (1987)	296	1.0
Sweden (1989)	2,890	3.1	**Yugoslavia** (1989)	1310	1.2	**Mexico** (1987)	183	0.2

Note: Data are for the most current year available (in parentheses). Countries differ in statistical collection capabilities and definitions. In addition, some R&D/gross national product percentages are R&D/gross domestic product. Foreign currency conversions to U.S. dollars were calculated with Organization for Economic Cooperation & Development purchasing power parities or using International Monetary Fund average-for-period par/market exchange rates. a Data are for former West Germany. **Source:** National Science Foundation

TOTAL AND NONDEFENSE R&D: Japan's R&D spending doubled in past decade

$ Billions, constant 1982	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	1979	Annual change 1988–89	Annual change 1979–89
TOTAL R&D													
U.S.	$111.1	$110.2	$106.8	$104.9	$102.5	$93.8	$85.8	$80.0	$76.6	$73.3	$70.1	1%	5%
Japan	45.9	42.0	39.1	36.5	36.1	32.6	30.1	27.7	25.8	23.4	21.2	9	8
Germany[a]	21.9	20.6	20.2	19.3	18.8	17.0	16.0	16.5	16.1	15.5	15.2	6	4
France	15.0	14.4	13.8	13.3	13.1	12.7	12.0	11.7	10.9	9.9	9.6	4	5
U.K.	13.2	13.5	13.6	13.5	12.8	na	11.9	na	12.2	na	na	−2	na
NONDEFENSE R&D													
U.S.	$ 78.7	$ 76.5	$ 72.7	$ 72.6	$ 71.9	$67.1	$62.2	$59.3	$58.0	$55.6	$52.8	3%	4%
Japan	45.5	41.7	38.8	36.2	35.9	32.4	29.9	27.5	25.7	23.4	21.2	9	8
Germany	20.9	19.7	19.2	18.3	17.9	16.2	15.3	15.8	15.4	14.7	14.4	6	4
France	11.8	11.2	10.8	10.6	10.5	9.9	9.4	9.1	8.2	7.7	7.5	5	5
U.K.	10.4	10.9	10.7	10.1	9.1	na	8.5	na	8.7	na	na	−5	na

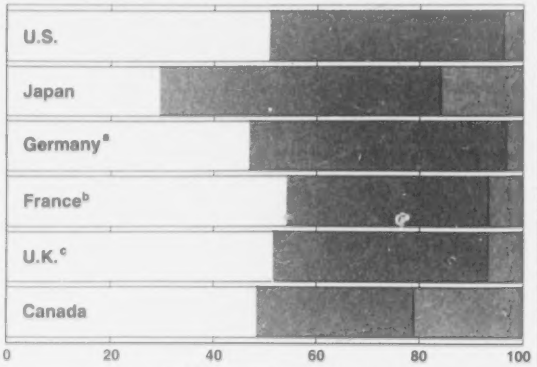
Note: Foreign currency conversions to U.S. dollars are calculated based on Organization for Economic Cooperation & Development purchasing power parity exchange rates. a Data are for former West Germany. na = not available. **Source:** National Science Foundation

ORIGIN OF CHEMICAL LITERATURE: Japan and China post steadily rising shares

% of total[a]	1990	1986	1982	1978	1974
U.S.	27.9%	27.7%	27.1%	26.6%	26.1%
U.S.S.R.	12.5	13.0	17.6	20.4	25.3
Japan	12.1	11.5	10.2	9.5	7.4
West Germany[b]	6.2	6.1	6.1	6.2	5.5
U.K.	5.5	5.6	5.9	6.0	6.0
China	4.5	3.1	1.8	0.2	0.0
France	4.2	4.3	4.1	4.0	4.2
Canada	3.0	3.1	2.7	2.6	2.7
India	2.9	3.0	3.3	3.0	2.6
Italy	2.3	2.4	2.3	2.0	2.0
Poland	1.5	1.8	1.5	2.2	2.1
Netherlands	1.5	1.4	1.3	1.2	1.0
Spain	1.5	1.3	0.9	0.6	0.5
Australia	1.2	1.3	1.3	1.3	1.1
East Germany[b]	1.2	1.2	1.2	1.4	1.1
Sweden	1.1	1.2	1.1	1.1	1.1
Czechoslovakia	1.0	1.2	1.3	1.4	1.6
Switzerland	1.0	1.1	1.1	1.0	1.0
All others	8.9	9.7	9.2	9.3	8.7
TOTAL PAPERS (THOUSANDS)	394.9	384.1	381.3	363.1	271.9

a Source of journal literature abstracted in *Chemical Abstracts* based on author's address. b Statistics for 1990 for entire year, even after reunification. **Source:** Chemical Abstracts Service

Industry provides the largest share of R&D funding in Japan and Germany



a Data are for former West Germany. b Estimated. c Data are for 1988.
Sources: Organization for Economic Cooperation & Development, National Science Foundation, individual nations